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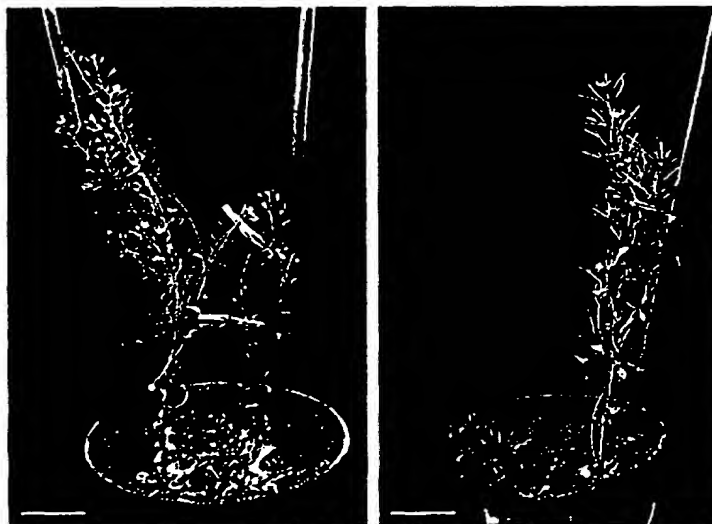
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## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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**(54) Title:** CONTROL OF FLOWERING**(57) Abstract**

The invention relates to control of flowering and reproduction in plants, and in particular to agents and methods for inducing or suppressing flowering. The invention provides isolated nucleic acid molecules which are useful for inducing flowering, particularly initiating early flowering, for delaying or suppressing flowering, or for manipulating the flowering period. In a first aspect, the invention provides an isolated nucleic acid molecule comprising a MADS box, which is capable of altering the flowering time of a plant. Preferably the nucleic acid molecule of the invention comprises a nucleotide sequence corresponding to a *FLOWERING LOCUS F (FLF)* gene. The nucleic acid molecule may be a genomic DNA, a cDNA, or a messenger RNA. The invention is applicable to any dicotyledonous or monocotyledonous plant species, including but not limited to decorative flower, vegetable, fruit, cereal, grass, tree, and other flowering species.

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CONTROL OF FLOWERING

This invention relates to the control of flowering and reproduction in plants, and in particular to agents and methods for inducing or suppressing flowering. The invention provides isolated nucleic acid molecules which are useful for inducing flowering, particularly initiating early flowering, for delaying or suppressing flowering, or for manipulating the flowering period.

DETAILED DESCRIPTION OF THE INVENTION

The initiation of flowering in a plant occurs in response to internal signals, such as physiological age or levels of plant growth regulators, or may result from changes in environmental conditions such as day length or low temperature. It is well known that in a variety of plant species a crucial factor is day length, also known as photoperiod. In many plant species, including several ecotypes of the widely-used model plant species *Arabidopsis thaliana*, flowering is promoted by long day photoperiod, or by a period of low temperature (vernalization) (Napp-Zinn, 1985).

Control of flowering in both horticultural and crop plants represents a major problem in the agricultural industry, and is also a problem in forestry. Significant losses in yield of plants may result if non-uniform flowering of plants occurs; this applies both to field-grown and to glasshouse-grown plants. The problem is particularly acute for field-grown plants, which are frequently exposed to abnormal or unseasonal conditions which may result in induction of flowering at an inappropriate time. Efficient plant production requires the synchronization of flowering time between pollen donor and pollen receptor plants, and is particularly important to maximize market opportunities for glasshouse-grown plants.

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Currently-available methods for regulation of flowering in plants are expensive and labour-intensive, and require the use of plant growth regulators, and/or controlled planting regimes and controlled-environment growth conditions. Consequently there is a need in the art for more efficient, cost-effective methods for controlling flowering time. These methods are applicable to a variety of commercially-significant plants species, including both horticultural plants, particularly those used in the cut-flower industry, and vegetable, cereal and other crop plants.

A class of genes known as MADS box genes encodes proteins which comprise a distinctive conserved DNA binding domain, known as the MADS box, which in certain cases has been demonstrated to bind to CC(A/T)<sub>6</sub>GG DNA motifs. The MADS box genes encode a class of transcription factors, which was first identified in yeast and in mammals. Subsequently similar transcription factors were identified in a range of plants, including *Arabidopsis thaliana*, *Antirrhinum majus*, tomato, tobacco, petunia, corn, *Pinus* species and *Eucalyptus* species. In plants, the MADS box genes have a "K domain", which resembles the coiled-coil domains of keratin proteins, which are implicated in protein/protein interactions, an intervening (I) domain, and a carboxy terminal (C) domain. In plants the principal role of MADS box genes is in specifying inflorescence meristem identity, and floral organ identity and development. Certain MADS box genes have also been implicated as having roles in root and vegetative development.

We have now identified nucleic acid sequences comprising a MADS box in the model plant *Arabidopsis thaliana* which play a role in the control of flowering time. The effect on flowering depends on the degree of expression of the nucleic acid sequences.

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SUMMARY OF THE INVENTION

In a first aspect, the invention provides an isolated nucleic acid molecule comprising a MADS box, which is capable of altering the flowering time of a plant.

5 In one preferred embodiment, the invention provides an isolated nucleic acid molecule which is capable of delaying the flowering of a plant. Preferably expression of the nucleic acid molecule in the plant, in the sense orientation under the control of a promoter  
10 sequence, is capable of delaying the flowering of the plant.

In a second preferred embodiment, the isolated nucleic acid molecule of the invention is capable of accelerating the flowering of a plant. Preferably  
15 expression of the nucleic acid molecule in the plant in the anti-sense orientation under the control of a promoter sequence is capable of accelerating the flowering of the plant.

Preferably the nucleic acid molecule of the invention comprises a nucleotide sequence corresponding to  
20 a *FLOWERING LOCUS F* (*FLF*) gene. The nucleic acid molecule may be a genomic DNA, a cDNA, or a messenger RNA.

More preferably the nucleic acid molecule comprises the nucleotide sequence set out in any one of SEQ  
25 ID NOS. 1, 2, 4, and 6 to 15, or a nucleic acid molecule capable of hybridizing thereto under at least low stringency hybridization conditions, or a nucleic acid molecule with at least 70% sequence identity to at least one of SEQ ID NOS. 1, 2, 4 and 6 to 15. Methods for  
30 assessing ability to hybridize and % sequence identity are well known in the art. Even more preferably the nucleic acid molecule is capable of hybridizing thereto under high stringency conditions, or has at least 80%, most preferably at least 90% sequence identity. A nucleic acid molecule  
35 having at least 70%, preferably at least 90%, more preferably at least 95% sequence identity to one or more of these sequences is also within the scope of the invention.

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In a second aspect, the invention provides a vector comprising a nucleic acid molecule according to the invention. The vector may be a virus, bacteriophage, plasmid, or bacterium. In a particularly preferred  
5 embodiment, the vector is a T-DNA vector present in a bacterium of the genus *Agrobacterium*, in particular *Agrobacterium tumefaciens*.

In a third aspect, the invention provides a plant cell transformed with a nucleic acid of the invention.

10 In a fourth aspect, the invention provides a plant transformed with a nucleic acid molecule of the invention.

In a fifth aspect, the invention provides a method of isolating a nucleic acid molecule capable of  
15 altering the flowering time of a target plant, comprising the step of using a nucleic acid molecule of the invention, or a functional portion thereof, as a hybridisation probe or polymerase chain reaction (PCR) primer, and optionally detecting hybridisation. Suitable methods are very well  
20 known in the art. For example, we have demonstrated that the *Arabidopsis* *FLF* sequence described herein can be used to isolate the homologous sequence from *Brassica napus*.

In a sixth aspect, the invention provides an *FLF* polypeptide. Preferably the polypeptide is encoded by a  
25 nucleic acid molecule of the invention. More preferably the polypeptide has an amino acid sequence as set out in any one of SEQ ID NO: 3, 5, and 16 to 30, or has a sequence at least 70% identical thereto.

The polypeptide may be produced by expression of  
30 the *FLF* nucleic acid molecule in a convenient host, for example in a bacterial host such as *Escherichia coli*. Antibodies against the polypeptide, including monoclonal antibodies, may be produced using routine methods, and it will be clearly understood that antibodies to the *FLF*  
35 polypeptide are within the scope of the invention. Such antibodies are useful for screening plants for high or low levels of expression of *FLF* polypeptide. Suitable

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screening methods including Western blotting and various forms of immunoassay, for example radioimmunoassay, ELISA, and chemiluminescent or fluorescent detection immunoassays.

Genes controlling developmental stages in plants, such as the gene associated with the nucleic acid of the invention, are highly conserved during evolution. Consequently the nucleic acid molecules and the methods of the invention are applicable to all plant species, whether the species is monocotyledonous or dicotyledonous. Thus the invention is generally applicable to flowering plants, including but not limited to ornamental, horticultural, agricultural and tree species. Methods for introducing exogenous DNA into plants of all these types, and for *in vitro* culture of plant tissue and regeneration of plant cells or tissues into whole plants, are known in the art. Methods for further generation and selection of commercially useful cultivars are also well known. Depending on the type of plant, it may be desirable to accelerate flowering ie. to induce early flowering, to synchronise flowering, to delay flowering or to suppress flowering.

For example it is desirable to suppress or delay flowering in many vegetable plants, in pasture grasses such as rye grass, or in sugar cane. Acceleration of flowering by induction of early flowering is desirable in a number of crop species, such as cotton, and in horticultural species.

We have surprisingly found that flowering can be delayed in proportion to the degree of expression of the nucleic acid molecule of the invention, and that early flowering can be induced by reducing the expression of this nucleic acid molecule.

Thus in a sixth aspect the invention provides a method of delaying flowering in a plant, comprising the step of introducing a nucleic acid molecule of the invention into cells of the plant, optionally such that expression of the nucleic acid molecule is under the control of an inducible promoter, and over-expressing the

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nucleic acid molecule. Preferably the promoter is a tissue-specific promoter.

Preferably flowering is delayed for at least five days, preferably for at least twenty days, and more preferably for at least thirty days beyond the normal flowering period. Most preferably flowering is delayed for at least forty to fifty days. In at least some species it may be possible to achieve complete suppression of flowering. It will be appreciated that this further provides a method of inducing sterility in a plant.

According to a seventh aspect, the invention provides a method of inducing early flowering in a plant, comprising the step of reducing the degree of expression in the plant of a nucleic acid molecule of the invention. The reduction may be effected by any convenient means, including but not limited to transformation of the target plant with an anti-sense nucleic acid sequence, post-transcriptional gene silencing, ribozyme cleavage, disruption of the nucleic acid sequence using a transposable element or transposon, or by a procedure such as vernalisation. The person skilled in the art will readily be able to select the most suitable procedure for the particular plant species in question. Optionally the method of the invention may be supplemented by other treatments, such as an exogenous gibberellin.

Preferably flowering is at least five days earlier than the normal flowering period, more preferably at least ten days, and most preferably at least fifteen days earlier than the normal flowering period.

We have found that the degree of expression of *FLF*, and hence the flowering time, can be altered by modifying the activity of genes known to affect flowering time, including but not limited to *FCA*, *FVE*, *FPA*, *LD*, *FLD*, and *VRN2*. Therefore in both the sixth and seventh aspects of the invention, a further means of modifying the degree of expression of *FLF* is provided by modifying the activity

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of one or more additional genes which affects flowering time, or vernalisation.

According to an eighth aspect, the invention provides a method of modifying the vegetative and/or floral phenotype of a plant, comprising the step of increasing the  
5 level of expression of an *FLF* gene, thereby to modify the level of production or activity of a gibberellin in the plant.

Preferably the vegetative or floral phenotypic  
10 characteristic is one which is regulated by gibberellic acid production or activity. More preferably the characteristic is related to plant architecture or fertility. For example, modification of gibberellic acid production and/or activity using the method of this aspect  
15 of the invention may be used to produce dwarf or sterile plants. In one particularly preferred embodiment, the invention provides sterile plants. In a second preferred embodiment, the invention provides dwarf plants; more preferably the plant is a wheat plant.

In a number of embodiments of the invention, the  
20 nucleic acid molecule of the invention is operably linked to a promoter sequence capable of regulating the expression of the nucleic acid molecule; more preferably the promoter sequence is adapted to regulate expression in a eukaryotic  
25 cell, most preferably a plant cell. The nucleic acid molecule of the invention may also be operably linked to a transcriptional terminator sequence.

Suitable promoter sequences are well known in the art, and include but are not limited to the CaMV 35S  
30 promoter, a NOS promoter, the octopine synthetase (OCS) promoter, a subclover stunt virus promoter and the *Arabidopsis thaliana* ubiquitin gene promoter. The person skilled in the art will readily be able to select the most suitable promoter for a given purpose. In particular,  
35 for some purposes an inducible promoter may be desirable, and these are also well known in the art. Suitable transcriptional terminator sequences active in plant cells

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are also well known, and may be of bacterial, fungal, viral, animal or plant origin.

Suitable transcriptional terminators particularly suitable for use in the present invention include the  
5 nopaline synthase (NOS) gene transcriptional terminator of *Agrobacterium tumefaciens*, the transcriptional terminator of the Cauliflower mosaic virus (CaMV) 35S gene, the zein gene transcriptional terminator from *Zea mays*, and the Rubisco small subunit (SSU) gene transcriptional terminator  
10 sequences or subclover stunt virus (SCSV) gene sequence transcriptional terminators.

The nucleic acid molecule of the invention may be introduced into a plant cell or tissue by any suitable means. A variety of methods for introducing exogenous DNA  
15 into plant tissue (transformation) are known. These include, but are not limited to, direct DNA uptake into protoplasts (Krens et al, 1982; Paszkowski et al, 1984), polyethyleneglycol-mediated uptake to protoplasts (Armstrong et al, 1990), electrophoresis (Fromm et al,  
20 1985), microinjection of DNA (Crossway et al, 1986), microparticle bombardment of tissue explants or cells (Christou et al, 1988; Sanford, 1993), or T-DNA-mediated transfer from *Agrobacterium* to the plant tissue. Representative T-DNA vector systems are described in the  
25 following references: An et al (1985); Herrera-Estrella et al (1983a, b); Herrera-Estrella et al (1985). These transformation methods are applicable to plant tissue culture, or may be employed with whole plants (*in planta* transformation). Again a person skilled in the art will be  
30 able to select the most suitable method for any given plant.

Any plant tissue capable of subsequent clonal propagation, whether by organogenesis or embryogenesis, may be transformed with a vector of the present invention. The  
35 particular tissue chosen will vary, depending on the clonal propagation systems which are most suitable for the species being transformed. Suitable tissue targets include whole



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plant, leaf discs, pollen, embryos, cotyledons, hypocotyls, megagametophytes, callus tissue, existing meristematic tissue (eg. apical meristem, axillary buds, and root meristems), and induced meristem tissue (eg. cotyledon  
5 meristem and hypocotyl meristem).

The vector of the invention may additionally comprise a dominant selectable marker to facilitate cell selection and plant breeding. A variety of suitable markers is known in the art, including but not limited to  
10 the *NPTII* gene, genes encoding resistance to an antibiotic such as hygromycin or ampicillin or to a herbicide such as phosphinothricin or glyphosate; a gene encoding a polypeptide which confers stress tolerance, such as  
15 superoxide dismutase; or a visually-detectable marker, such as green fluorescent protein or  $\beta$ -glucuronidase. The person skilled in the art will readily be able to select the most suitable marker for use in a specific case.

The invention is applicable to any dicotyledonous or monocotyledonous plant species, including but not  
20 limited to decorative flower, vegetable, fruit, cereal, grass, tree, and other flowering species. Preferably the plant is selected from the group consisting of chrysanthemum, rose, gerbera, carnation, tulip, legumes such as soya bean, sugar beet, lettuce, cotton, oil seed  
25 rape, coriander, *Lolium*, wheat, barley, maize, rice, pasture grasses, *Phalaris*, Canola and other *Brassica* species, *Linola* species, sugar cane, *Eucalyptus* species, pine and poplar. Forest species are to be understood to be within the scope of the invention.

30 For the purposes of this specification it will be clearly understood that the word "comprising" means "including but not limited to", and that the word "comprises" has a corresponding meaning.

The term "flowering time" as used herein means  
35 the time at which floral meristem tissue is first visually detectable in the plant, for example by light microscopy or using the naked eye. The measured flowering-time includes

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the time taken for the occurrence of the cellular processes in the differentiation of a floral meristem and subsequent cell divisions which enable such visual means to be used. The term "flowering time" also includes the time taken for the transition from a vegetative meristem to a floral meristem to occur, as measured visually, following the induction of flowering in the plant by the application thereto of a specific chemical, physical or environmental stimulus, such as a plant growth regulator, photoperiod or temperature regime, including the vernalisation of the plant. Alternatively flowering may be induced in response to an internal development signal in the plant. Those skilled in the art will be aware of the specific nature of such chemical, physical or environmental stimuli or internal developmental signals.

"Altering the flowering time" means that the time period in which floral meristem tissue is first visually detected in a plant is increased, decreased, or otherwise modified or regulated. Thus, flowering may be delayed, accelerated, inhibited, suppressed, or synchronized.

The term "meristem" refers to plant tissue in which cells are undergoing, or are capable of undergoing, rapid mitotic division followed by differentiation into cell types which are capable of forming a primordium which develops into an organ such as a leaf, root, stem, floral bud or other plant organ.

"Vegetative meristem" refers to a meristem in which the differentiation process produces a cell type which develops into a vegetative organ or non-reproductive organ, such as a leaf, petiole, bract, stem or root.

"Floral meristem" refers to a meristem in which the differentiation process produces a cell type which develops into an inflorescence meristem, a secondary inflorescence meristem, a floral organ or sexual reproductive organ, in which the meristem or organ, when developed, may comprise both reproductive and non-reproductive tissues, including, but not limited to,

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anthers, stamens, stigmas, ovules, carpels, petals and sepals. "Bolt" refers to an inflorescence stem of a rosette plant, and "bolting" is the development of such a stem.

5           The term "derived from" means that a particular integer or group of integers has originated from a particular organism or species as specified herein, but has not necessarily been obtained directly from that source.

Representative low and high stringency conditions  
10 of hybridisation as referred to herein are as follows:

High stringency: hybridization at 42°C in 50% formamide, 3 x SSC, 0.1% SDS, 20 x Denhardt's, 50 µg/ml salmon sperm DNA overnight and washed with a final wash of 0.1 x SSC, 0.1% SDS at 42°C.

15           Low stringency: hybridization at 28°C in 50% formamide, 3 x SSC, 0.1% SDS, 20 x Denhardt's, 50 µg/ml salmon sperm DNA overnight and washed with a final wash of 0.1 x SSC, 0.1% SDS at room temperature.

A "homologue" of a nucleotide sequence refers to  
20 an isolated nucleic acid molecule which is substantially the same as the nucleic acid molecule of the present invention or its complementary nucleotide sequence, despite the occurrence within the sequence of one or more nucleotide substitutions, insertions, deletions, or  
25 rearrangements.

An "analogue" of a nucleotide sequence means an isolated nucleic acid molecule which is substantially the same as a nucleic acid molecule of the present invention or its complementary nucleic acid, despite the occurrence of  
30 any non-nucleotide constituents not normally present in the isolated nucleic acid molecule, for example carbohydrates, radiochemicals including radionucleotides, reporter molecules including, but not limited to digoxigenin, alkaline phosphatase or horseradish peroxidase.

35           A "derivative" of a nucleotide sequence means any isolated nucleic acid molecule which contains significant sequence similarity to the molecule or a part thereof. The

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person skilled in the art will appreciate that the nucleotide sequence of the present invention may be subjected to mutagenesis to produce one or more single or multiple nucleotide substitutions, deletions and/or  
5 insertions. Nucleotide insertional derivatives of the nucleotide sequence of the present invention include 5' and 3' terminal fusions, as well as intra-sequence insertions of single or multiple nucleotides or nucleotide analogues. Insertional nucleotide sequence variants are those in which  
10 one or more nucleotides or nucleotide analogues are introduced into a predetermined site in the nucleotide sequence of the sequence, although random insertion is also possible; suitable screening of the resulting product is performed. Deletional variants are characterised by the  
15 removal of one or more nucleotides from the nucleotide sequence. Substitutional nucleotide variants are those in which at least one nucleotide in the sequence has been removed, and a different nucleotide analogue inserted in its place.

20 Reference in this specification to a "gene" is to be understood in its broadest context, and includes:

(i) a classical genomic sequence comprising transcriptional and/or translational regulatory sequences and/or a coding region and/or non-translated sequences (ie.  
25 introns and 5'- and 3'-untranslated sequences);

(ii) mRNA or cDNA corresponding to the coding regions (ie. exons), optionally additionally comprising 5'- or 3'-untranslated sequences of the gene; or

(iii) an amplified DNA fragment or other  
30 recombinant nucleic acid molecule produced *in vitro*, and comprising all or a part of the coding region and/or 5' or 3'-untranslated sequences of the gene.

The term "gene" is also used to describe synthetic or fusion molecules encoding all or part of a  
35 functional product. A functional product is one which comprises a sequence of nucleotides or is complementary to a sequence of nucleotides which encodes a functional

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polypeptide, in particular the *FLF* polypeptide of the invention or a homologue, analogue or derivative thereof.

In some of the examples herein the *FLF* gene is referred to as gene B. These two terms are synonymous.

5

#### BRIEF DESCRIPTION OF THE FIGURES

Figure 1 is a photograph showing wild-type C24 (left), the late flowering T-DNA tagged *flf* mutant (middle) at 70 days after germination, and *flf* mutant at 150 days, showing the domed shape caused by vegetative bolts (right). The bar represents 5 cm.

Figure 2 shows segregation of two T-DNA inserts with the late flowering phenotype

**A.** Genomic DNA isolated from a T<sub>2</sub> population segregating for early (E), late (L) and very late (VL) flowering, digested with *EcoRI* and probed with the *NPTII* gene.

**B.** Physical map of the two T-DNA inserts linked to the *FLF* locus, showing their orientation. *EcoRI* sites are labelled RI; LB and RB represent the left and right borders, respectively, of the T-DNA. The triangle symbol represents the site of deletion of 30 bp to the right of the T-DNA. The arrows represent the direction of transcription of the genes.

**C.** Representation of a 27 kb region of *Arabidopsis* mutant DNA containing the gene A and gene B loci, showing the location of the T-DNA inserts. DNA fragments from the flanking plant DNA (probes 2 and 3) were used as probes to isolate cDNA clones. *HindIII* (H), *BamHI* (B) and *EcoRI* (R1) restriction enzyme sites are indicated. The positions of gene A and gene B are shown, and their directions of transcription are indicated by arrows.

**D.** The 6.5kb and 6.8 kb *BamHI* fragments, isolated from a genomic library of wild-type C24 with probes 1 and 2 from Figure 2C, spanning the site of the T-DNA insertions. Restriction sites are as in Figure 2C.

35

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Figure 3 shows levels of expression of gene A and gene B in 30 day old wild-type C24 plants (lane 1), hemizygous (lane 2) and homozygous (lane 3) *flf* mutant plants.

5           Figure 4 is a photograph showing 35S::*FLF* T1 transgenic plants in C24 (left) and Landsberg *erecta* (right) ecotypes. The C24 transgenics were either early-flowering (back) or late-flowering (front). The Landsberg *erecta* transgenics were either late-flowering (left) or  
10   flowered at normal time (right).

Figure 5 shows the *FLF* gene structure and the expression pattern of the *FLF* transcript

A.       Genomic structure of the *FLF* gene, showing location and size of introns and location of the MADS box,  
15   intervening domain (I), K domain (K) and carboxy terminal domain (C). The numbers below the line represent the number of base pairs in each exon.

B.       Pattern of expression of *FLF* mRNA in C24 plants: roots (R) and rosette leaves (RL) from *in vitro*  
20   grown vegetative plants, cauline leaves (CL), bolt stems (BS), floral apex and buds (B) from soil grown plants with bolt stems between 1 and 5 cm. Mature flowers (F) and siliques (S) were collected from older plants. Plants were grown under 16 h photoperiod conditions. The RNA gel blots  
25   for B-F were probed with a riboprobe transcribed from the *FLF* (Gene B) cDNA clone linearised to remove the MADS box region. The ethidium bromide-stained ribosomal bands are shown as a loading control in B-F.

C.       Expression level of *FLF* mRNA in whole C24  
30   or *flf* mutant plants, harvested every 10 days (as indicated by the numerals) until the majority of the C24 plants were bolting (50 days under these growth conditions).

D.       Expression of *FLF* mRNA in C24 (lane 1-6) and *flf* (lane 7-12) plants grown for 21 days in 8 h  
35   fluorescent photoperiod, and then at the end of the 21<sup>st</sup> photoperiod either kept in the same conditions (SD; lane 1, 2, 7, 8) or transferred to continuous dark (CD; lanes 3, 4,

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9, 10) or continuous light (CL; lanes 5, 6, 11, 12). Plants were harvested either just prior to what would have been the start of the following photoperiod (dawn; lane 1, 3, 5, 7, 9, 11), or just prior to the end of the photoperiod (dusk; lanes 2, 4, 6, 8, 10, 12). Transcript levels were a little higher at the start of the photoperiod, but this pattern was not altered in the mutant.

**E.** Effect of gibberellic acid ( $GA_3$ ) treatment and vernalization on the *FLF* transcript in C24 (lanes 1-3) and *flf* mutant (lanes 4-6) seedlings. RNA was isolated from 12 day old seedlings that had either had no treatment (C; lanes 1 and 4), been grown on medium containing  $10^{-5}$  M  $GA_3$  (G; lanes 2 and 5) or had a pretreatment of 3 weeks at 4°C (V; lanes 3 and 6).

**F.** *FLF* expression in rosette leaves of C24 and the early-flowering antisense methyltransferase line 10.5 (T3 generation) harvested soon after bolting.

Figure 6 shows

**A.** Genomic DNA isolated from individual *flf*, *efSL3* (M2), *efSL4* (M2) and C24 plants digested with *EcoRI* and probed with a probe directed to the 3' region of *Ac*. The DNA for the *flf* sample was extracted from plants which contained a third T-DNA band, hence the band at about 8 kb. The presence of this third band had no effect on flowering time, and is therefore irrelevant.

**B.** As for **A**, except that the probe was probe 4 (see Figure 2C). The DNA for the *efSL3* (M2) and *efSL4* (M2) samples was extracted from bulked M2 plants which contained neo-lates as well as early-flowering mutants. Therefore there is some of the 2.7 kb band present in these DNA extracts. Other DNA isolated from individual early-flowering plants does not contain a band at 2.7 kb.

**C.** Location of *Ac* insertion in intron I. The nucleotide positions are given below, taking the A of the ATG as nucleotide 1.

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D. Expression level of *FLF* gene in 15 day old rosette leaves of C24 (lane 1), *flf* (lane 2), *ef* SL3 (lane 3), *ef* SL4 (lane 4). The M2 early flowering mutants had just started to bolt, whereas the other plants remained vegetative. The ethidium bromide-stained ribosomal bands are shown as a loading control.

Figure 7 shows gel blots from neo-late plants.

A. Genomic DNA was isolated from the 6 neo-late mutant plants and from *ef*SL3 (M2), *ef*SL4 (M2), *flf* and C24 plants, and digested with *Eco*RI. The DNA gel blot was probed with the 3' region of *Ac*.

B. Total RNA was isolated from a mixture of rosette and cauline leaves from the 6 neo-late plants, *flf* and C24. The RNA gel blot was probed as in Figure 5. The ethidium bromide-stained ribosomal bands are shown as a loading control.

Figure 8 shows expression of the *FLF* gene in ecotypes and late-flowering mutants.

Total RNA was extracted from 12 d old seedlings and RNA gel blots were probed as in Figure 5. The ethidium bromide-stained ribosomal bands are shown as a loading control in A-C.

A. Expression in a number of different *Arabidopsis* ecotypes

B. Expression in Landsberg *erecta* (L.er.) and Landsberg *erecta* lines which contain late alleles at either the *FRI* (L.er.-*FRI*<sup>Sf2</sup>) or *FLC* (L.er.-*FLC*<sup>Sf2</sup>, L.er.-*FLC*<sup>col</sup>) loci.

C. Expression in late-flowering mutants in either L.er. ecotype (*fca*, *fve*, *fpa*, *gi*, *co*, *fha*, *fwa*, *fd*, *fe*, *ft*) or *Ws* (*ld*). The mutants *vrn1* and *vrn2* were isolated in the *fca* background, and only *vrn1* has been segregated away from the *fca* mutant locus.

Figure 9 shows the partial genomic sequence of an *FLF*-like sequence from *Brassica napus*, showing the location



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of exons, and the predicted sequence of the translated product.

Figure 10 shows a comparison of the predicted translated product of a *Brassica napus* FLF-like sequence (top lines), and the predicted FLF translation product from *Arabidopsis thaliana*, showing identical amino acids (|), highly conserved amino acids (:), and conserved amino acids (.) .

## 10 DETAILED DESCRIPTION OF THE INVENTION

The invention will now be described in detail by way of reference only to the following non-limiting examples, and to the figures.

## 15 **GENERAL METHODS**

### **Plant Material and Growth Conditions**

*Arabidopsis* was grown either in pots containing a mixture of 50% sand and 50% loam, or aseptically in test-tubes or petri dishes containing a modified Murashige and Skoog (MS) medium (Langridge, 1957). Unless otherwise stated, all plants were grown in artificially lit cabinets at 21° or 23°C, under long day (16 hr light, 8 hr dark) conditions using cool white fluorescent lights at an intensity of 200  $\mu\text{M m}^{-2}\text{s}^{-1}$ .

Plants were vernalized by germinating seed in the dark for either 3, 4 or 8 weeks at 4°C. Following this cold treatment, seedlings were transferred to long day photoperiods at 23°C and times to flower, measured as the time until stem elongation (bolting) was observed, were determined, beginning from the first day at the higher temperature.

### ***Arabidopsis* Transformation**

*Arabidopsis* was transformed either by root transformation (Valvelkens et al., 1988) for the generation of the *flf* mutant and gene A transgenic plants, or by *in planta* transformation (Bechtold et al, 1993) for the gene B

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transgenic plants. The late-flowering mutant (*flf*) arose during transformation of the early-flowering ecotype C24 with a modified binary vector pBinΔAc (Finnegan et al, 1993). This vector contains the neomycin

5 phosphotransferase II (*NPTII*) gene under the control of the nopaline synthase (*NOS*) promoter, together with a deleted maize Ac transposable element inserted within the untranslated leader of the  $\beta$ -glucuronidase gene, in the reverse orientation to the direction of transcription.

10

Example 1      Identification of a Mutant Locus Associated  
With a Late Flowering Phenotype

Following transformation of the *Arabidopsis thaliana* ecotype C24 with a T-DNA construct containing an  
15 Ac transposable element, individual T<sub>0</sub> plants, resistant to kanamycin, were allowed to self-pollinate, and the T<sub>1</sub> progeny screened for families that flowered significantly later than parental C24 plants.

Some of the plants of family 14-58 flowered after  
20 70 days compared to 30 days for the C24 control plants. Segregation analysis of the progeny of a selfed late-flowering T<sub>1</sub> plant from family 14-58, showed 53 "late" (flowering time >70 days) compared to 15 "early" flowering plants (flowering time 30 days). The result fits a 3:1  
25 segregation ratio ( $\chi^2=0.313$  P>0.5), and is consistent with the late-flowering phenotype being a consequence of a single mutation. We have designated the mutant locus *FLOWERING LOCUS F (FLF)*.

Within the segregating progeny, the late-  
30 flowering plants could be further differentiated into two classes; "lates", flowering between 70 to 90 days and "very lates", which flowered later than 150 days. Some of the "very late" plants had not flowered after a year of growth. The "very late" *flf* mutant, shown in Figure 1, produced  
35 leaves at a rate similar to non-transformed C24, and had many more leaves at flowering than C24. After several months of growth, bolts arose from the internodes between

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rosette leaves. These bolts elongated approximately two to three cm and formed aerial rosette structures, giving the mutant plants a dome-like appearance, similar to that described for the *fld* mutant (Chou and Yang, 1998).

5           The late-flowering phenotype observed is more extreme than any of the previously-reported late-flowering mutants and ecotypes (Koornneef et al, 1991). Progeny tests showed that selfed "very lates" produced only "very late" progeny, whereas selfed "late" plants segregated 1:2:1 for  
10 very late, late and early flowering plants. This segregation pattern is consistent with a semi-dominant mutation, with the lateness in flowering being proportional to the level of gene product.

15   Example 2           Construction and Screening of Genomic Libraries

A genomic library of the *flf* mutant was constructed by partial digestion of total plant DNA with the restriction enzyme *Sau3AI* and ligation into the phage  
20 vector  $\lambda$ EMBL4. The resulting library was screened using a  $^{32}$ P-dCTP labelled probe of the *NPTII* gene (Feinberg and Vogelstein, 1983). Four positive phage clones were purified and restriction mapped. Together these spanned 27kb of plant DNA flanking the site of insertion of T-DNA.  
25 A 2.3kb *BamHI-EcoRI* and a 2.7 kb *EcoRI* fragment (probes 1 and 2 respectively, Figure 2C) isolated from this flanking plant DNA were subsequently used to probe a genomic library of wild-type *Arabidopsis* C24, made from *BamHI*-digested DNA and cloned into  $\lambda$ EMBL4. Probe 1 hybridized to a genomic  
30 clone containing 6.5kb of plant DNA spanning the T-DNA insertion site, and probe 2 hybridized to a genomic clone containing 6.8 kb of adjacent sequence.

Example 3           Isolation of the *FLF* Gene

35   Two T-DNAs segregate with the very late flowering phenotype  
The very late-flowering phenotype segregates with two T-DNA bands identifiable by Southern analysis, which

- 20 -

were designated bands 1 and 5. Southern blotting showed that bands 1 and 5 are inverted and adjacent:

RB  $\leftarrow$  LB LB  $\rightarrow$  RB  
                     1                    5  
 5  
 (LB, left border; RB, right border)

The size of the bands, combined with sequence analysis, places the smaller band (band 5) closest to the  
 10 *FLF* gene. Recombinant inbred lines were used to map the *FLF* region to the top of chromosome 5, 4 cM from RFLP marker 447. This places the *FLF* gene near *FLC*, a gene known to control flowering time in ecotypes of *Arabidopsis*.

A 27 kb segment of genomic DNA from the mutant  
 15 around the site of T-DNA insertion was mapped. C24 genomic clones covering 13 kb around the T-DNA insertion site in the mutant were sequenced. Two probes, on either side of the T-DNA insert, were used to screen cDNA libraries. A 4.6 kb EcoRI/BamHI fragment from a C24 genomic clone  
 20 (containing 4.4kb of sequence "upstream" of the T-DNA insertion site and 0.2 kb "downstream" of the T-DNA insertion site) was used to isolate cDNA clones identifying "gene A" as a transcribed region. A 2.7 kb EcoRI fragment, covering the region 0.4 kb "downstream" to 3.1 kb  
 25 downstream of the T-DNA inserts, was used to isolate cDNA clones identifying "gene B" as a transcribed region.

Comparison of part of the intergenic region sequence between ecotypes C24 and Ws revealed an insertion into the C24 DNA of an approximately 200 bp sequence,  
 30 420 bp to the "right" of the stop codon of gene A and 120 bp to the "left" of the T-DNA insertion. The sequence is present in both C24 wild-type and the *flf* mutant. The 200 bp insertion shows 100 % homology to ORF167 of the *Arabidopsis* mitochondrial genome. By PCR analysis we have  
 35 determined that this sequence is absent in Landsberg erecta and Columbia ecotypes. The significance of this inserted DNA segment is unknown.

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A map of the overall region is shown in Figure 2B.

#### Example 4      cDNA Libraries

5            In order to identify expressed genes closely  
linked to the T-DNA, three *Arabidopsis* cDNA libraries  
(Elledge et al, 1991; Weigel et al, 1992; Newman et al,  
1994) were screened, using probes to plant DNA around the  
T-DNA insertion site (probes 2 and 3, Figure 2C). Two  
10 classes of cDNA clones were isolated. These were  
respectively designated gene A and gene B. Gene B was  
subsequently re-designated as *FLF*. Two gene A cDNAs were  
isolated with a 4.6 kb EcoRI-BamHI fragment (probe 3,  
Figure 2C) from a screen of 200,000  $\lambda$ Yes clones; however,  
15 no clones were isolated with the 2.7 Kb EcoRI fragment  
(probe 2, Figure 2C). The gene A cDNAs were subcloned from  
the phage by site-specific recombination, using the CRE  
protein (provided by the *E. coli* strain BNN132) and the lox  
sites within the vector (Elledge et al, 1991). The larger,  
20 almost full-length gene A cDNA was further subcloned into  
pBluescript SK(-) (Stratagene). Full-length gene A cDNAs  
were subsequently isolated by screening a Landsberg *erecta*  
flower cDNA library (Weigel et al, 1992). The mutant and  
wild-type genomic clones corresponding to the isolated cDNA  
25 were also subcloned as smaller fragments into pBluescript  
SK(-). As no cDNA clones were isolated with probe 2  
(Figure 2C) from either cDNA library, a third library was  
screened. Four full-length gene B cDNA clones were  
isolated from a  $\lambda$ PRL2 cDNA library derived from different  
30 tissues and developmental stages (Newman et al, 1994). All  
cDNAs and the mutant and wild-type genomic clones were  
sequenced on both strands by the dideoxy chain termination  
method (Sanger et al, 1977) using fluorescent primers  
(Brumbaugh et al, 1988). The University of Wisconsin GCG  
35 software package was employed for sequence analysis  
(Devereux et al, 1984). The nucleotide and predicted

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protein sequences were used to search the GenBank database for any homologous sequences; none were found.

Example 5      Construction of 35S::gene A plasmid

5                    As the larger of the initially isolated gene A cDNA clones lacked the AT of the ATG of the start codon, oligonucleotide-directed mutagenesis was employed to generate a 200bp fragment from the 5' end of the cDNA which contained the absent nucleotides. Two oligonucleotides  
10 were synthesized on an Applied Biosystems DNA Synthesizer for this purpose:-

- (1)    5' AAG**CCGCGG**ACAATGGAAGCTGTAAGATGC 3'  
(2)    5' GAGAGGCTG**GTTA**ACCGGAG 3'.

15

                  The nucleotides indicated in bold show the locations of *Sac*II and *Hpa*I restriction sites within the primers. The amplification reaction was carried out in a 10 µl final volume that contained 2 µM of each  
20 oligonucleotide primer, 200pg of *Hind*III-cleaved cDNA as a template, 0.2 units of Taq polymerase and 125 µM of each of the four deoxynucleotides. Conditions for the amplification were as follows: 95°C for 2 mins, 5 cycles consisting of 15 s denaturation 95°C, annealing at 40°C for  
25 30 s, and polymerization at 72°C for 1 min, followed by 25 cycles where the annealing temperature was raised to 50°C for 15 sec and finally 30°C for 1 min. The resulting 200 bp PCR fragment was cloned into *Sac*II and *Hpa*I sites in the original cDNA plasmid, and then sequenced to ensure  
30 that no mutations had been introduced during the amplification procedure. Sense binary constructs were made by digesting the full length cDNA with *Eco*RI and *Sac*II, end filling the recessed termini using the Klenow fragment of DNA polymerase I, and ligating the released 1.4 kb fragment  
35 into the *Sma*I site of the expression vector pDH51 (Pietrzak et al, 1986). This places the expression of the *FLF* cDNA under the control of the CaMV 35S promoter. Recombinant

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plasmids, containing the cDNA in the desired orientation, were cleaved with *EcoRI* and cloned between the right and left border sequences of the binary vector pBin19 (Bevan, 1984). The binary construct was transferred to

5 *Agrobacterium tumefaciens* strain AGL1 (Lazo et al, 1991) by triparental mating, employing pRK2013 as the helper plasmid. Roots of wild-type C24 plants were transformed (Valvelkens et al, 1988) using the *NPTII* gene as a selectable marker to identify transgenic plants.

10

Example 6      Construction of 35S::gene B plasmid

A binary construct containing gene B under the control of the CaMV 35S promoter was generated by cloning a

15 cDNA clone as template with the primers, using methods similar to those described in Example 5:

5' CCGCTCGAGCTTAGTATCTCCGGCG 3' and  
5' GGACTAGTCGCCCTTATCAGCGGA 3',

20

in which restriction sites are shown in bold, and the sequence hybridizing to gene B cDNA is underlined, into *XhoI/SpeI* digested pART7 (Gleaves, 1992) containing the CaMV 35S promoter. The 35S::gene B cassette was then

25 subcloned using *NotI* into pART27 (Gleaves, 1992) and introduced into *A. tumefaciens* strain GV3101 (Koncz and Schell, 1986) as described above. Transgenic plants were generated by *in planta* transformation (Bechthold et al, 1993)

30

Example 7      DNA Gel Blot Analysis

Total genomic DNA was isolated either by following the cetyltrimethylammonium bromide (CTAB) procedure (Dean et al, 1992), or as described by McNellis

35 et al. (1998). 2-3 µg of DNA was digested with the appropriate restriction enzyme, electrophoresed on an 0.8% agarose gel, and blotted onto Hybond N+ membranes

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(Southern, 1975). Probes were labelled with  $^{32}\text{P}$ -dCTP using the random primer method (Feinberg and Vogelstein, 1983).

The NPTII probe was generated as described above. The 3'Ac probe was a SphI fragment (Lawrence *et al*, 1993), and probe 4 was generated by amplification of the wild-type genomic clone with primers:

5'-GTATAGGGCACATGCCC-3' and

5'-CACTCGGAGCTGTGCC-3'.

10

This results in a 570 bp subset of probe 2 sequence, lacking the MADS box, to eliminate cross-hybridization.

15 Example 8      RNA Extraction and RNA Gel Blot Analysis

Total RNA was extracted from approximately 1g of plant tissue, following the method of Longemann *et al*. (1987). 10-20  $\mu\text{g}$  of total RNA was electrophoresed on 2.2 M formaldehyde/agarose gels, and blotted onto Hybond N nylon filters. T7 or SP6 polymerase transcription of the linearised gene A or gene B plasmid template (containing the complete cDNA for gene A, linearised to remove MADS box for gene B) was used to generate antisense  $^{32}\text{P}$ -dUTP labelled riboprobes. Filters were hybridized as described by Dolferus *et al* (1994), washed with a final solution of 0.1xSSC, 0.1% SDS at 65°C. For gene A Northern blots it was necessary to treat filters with RNase A as previously described (Dolferus *et al*, 1994) to avoid ribosomal trapping. The filters were exposed to phosphor screens for quantification of signal intensity using a phosphorimager (Molecular Dynamics, USA). RNA size markers were used to determine the size of the gene A and gene B transcripts.

35 Example 9      RFLP Mapping

DNA from sixty-four recombinant inbred lines (Lister and Dean, 1993) was digested with *Bam*HI, and Southern blots were probed with gene A. The Mapmaker



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program was employed to compare the data with RFLP data for 68 mapped markers. Fine mapping of gene A was performed using DNA from F<sub>2</sub> plants generated from a cross between Landsberg erecta and the *flf* mutant. A *Hpa*I digest of 62  
5 F<sub>2</sub> DNA was probed with the chromosome 5 RFLP marker 447 (Chang *et al.*, 1988). A restriction fragment length polymorphism (RFLP) was found between the parental lines, Landsberg erecta and Columbia, by digestion of genomic DNA with *Bam*HI and probing with the gene A cDNA.

10

Example 10      Insertion Of Two Inverted and Adjacent T-DNAs  
Produces A Partial-Dominant Late Flowering  
Mutant

15                DNA gel blot analysis of a late flowering T<sub>1</sub> parent showed five T-DNA inserts. Figure 2A shows a DNA gel blot of 16 segregating progeny plants of a selfed, hemizygous mutant plant derived from this T<sub>1</sub> parent. In a total of 70 progeny, only two inserts segregated with the  
20 late-flowering phenotype (bands 1 and 5); "late" plants were hemizygous for these two T-DNAs, and "very late" plants were homozygous for the same two inserts. The two linked T-DNAs were segregated away from the other T-DNA inserts by backcrossing to non-transformed C24. Plants  
25 containing only the two T-DNA inserts (Figure 2A, bands 1 and 5) were identified by DNA gel blot analysis, and further analysis showed that the two inserts were adjacent and in inverted orientation (Figure 2B). DNA gel blot analysis, using probes derived from segments of the T-DNA  
30 construct and *Ac* demonstrated that no movement of the *Ac* transposable elements had occurred.

              A genomic DNA library from a late flowering plant containing only the two linked T-DNA inserts was screened with an *NPTII* probe to isolate DNA segments spanning the  
35 site of T-DNA insertion. Three overlapping clones were isolated from the left side of the T-DNA. The longest of these, together with one clone isolated from the right

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side, is depicted in Figure 2C. These clones accounted for a total of 27 kb of plant DNA spanning the site of the T-DNA insertion. C24 genomic clones were isolated from a genomic DNA library, which was prepared by digestion of total *Arabidopsis* DNA with the restriction enzyme *Bam*HI and ligation of the digest into the phage vector  $\lambda$ EMBL4, using probes 1 and 2 (Figure 2C). Clones containing a 6.5kb *Bam*HI fragment spanning the insertion site and a 6.8 kb *Bam*HI fragment downstream of the insertion site were characterized (Figure 2D). The genomic DNA sequence, cDNA sequence, and predicted protein sequence are set out in SEQ ID NO. 1, SEQ ID NO. 2 and SEQ ID NO. 3 respectively. The genomic DNA sequence includes about 2 kb of promoter sequence, and 6 introns.

The chromosomal location of the *FLF* region was determined using 64 F9 recombinant inbred lines and data for several known markers (Lister and Dean, 1993). The Mapmaker program located the *FLF* region to the top of chromosome 5, 4cM from the RFLP marker 447, placing the gene in the vicinity of three other genes, *TFL*, *FLC* and *EMF1*, which are involved in the regulation of flower initiation (Shannon and Meeks-Wagner, 1991; Lee et al, 1994b; Koornneef et al, 1994; Sung et al, 1992).

Example 11      Two Genes Flanking the T-DNA Inserts Have Increased Expression In The *flf* Mutant

Transcriptionally active regions in the plant DNA spanning the site of T-DNA insertion were identified by screening a cDNA library with probes derived from either side of the T-DNAs (probes 2 and 3, Figure 2C). Two overlapping partial-length cDNA clones were isolated with probe 3; full-length clones containing inserts of approximately 1.5 kb were isolated by screening a second cDNA library. Four identical full-length cDNA clones containing inserts of 1.0 kb were isolated with probe 2. Comparison of cDNA and genomic sequence revealed that the T-DNAs had inserted between the two transcribed regions,

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591 bp downstream of the polyadenylation site of gene A and 2.3 kb upstream of the start codon of gene B. Comparison of the mutant and C24 genomic sequences revealed a 30 bp deletion immediately downstream of the insertion site, with  
5 no further differences identifiable.

As neither gene was disrupted by the insertion of the T-DNAs, we investigated whether the expression of the genes was altered in the mutant. Figure 3A shows an RNA gel blot performed using RNA isolated from 30 d old leaf  
10 tissue of ecotype C24, and hemi- and homozygous *flf* mutant plants grown under identical conditions. As shown in Figure 3 antisense riboprobes specific for either gene A or gene B revealed that both genes are more highly expressed in the *flf* homozygote leaf tissue than in ecotype C24, with  
15 the 1.5 kb gene A transcript being approximately 10 times more highly expressed in the mutant and the 1.0 kb gene B transcript being approximately two-fold overexpressed in the homozygous mutant. The hemizygous mutant has an intermediate level of expression of both genes. Without  
20 wishing to be limited by any proposed mechanism, we believe that insertion of the T-DNA complete with Ac elements has caused this over-expression.

25 Example 12 Transgenic Plants Over-Expressing Gene B Have Altered Flowering Time

In order to determine which gene is responsible for the late-flowering phenotype, we transformed C24 with constructs containing either gene under the control of the CaMV 35S promoter. 49 transgenic lines were generated with  
30 the gene A construct, and flowering time was assessed in the T2 generation. The majority of the transgenic lines showed no variation from wild-type flowering time; however, a few lines were slightly late-flowering. As shown in Table 1, four of the transgenic lines were significantly  
35 later flowering than the C24 wild-type. However, there was no correlation between time to flowering and the level of gene A expression. 23 transgenic lines were generated with

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the gene B construct, and differences in flowering time compared to C24 were apparent in the T1 generation, ie. in the primary transformants. 17 T1 plants flowered earlier (range 15-25 d) than non-transformed C24 (30 d) under these conditions; eight of these showed either full or partial sterility. Four flowered at around the same time as C24, and two had not flowered after 90 d. Examination of the level of gene B mRNA transcript in kanamycin-resistant progeny of two early-flowering T1 plants, and rosette leaves from two late-flowering T1 plants, revealed a high level of gene B expression in all the transgenic plants.

Table 1

Flowering time of 35S::gene A transgenic plants

15

	Flowering time	Relative expression level of gene A mRNA
C24	29.9 $\pm$ 0.6	1
B2	38.3 $\pm$ 0.9	2
A53	35.8 $\pm$ 0.8	20
A54	38.4 $\pm$ 0.5	8
A93	35.4 $\pm$ 0.5	4
<i>flf</i>	>>50	10

Transgenic and *flf* mutant seeds were germinated on MS plates + 50  $\mu$ g/ml kanamycin, and C24 seeds were germinated on MS plates. At least 20 12 d seedlings were transplanted into individual soil pots and grown at 23°C under fluorescent lights (16 h light, 8 h dark). Flowering time was recorded as the number of days to stem elongation. Total RNA was extracted from 14 d *in vitro* grown seedlings and used for quantitation of *FLF* expression levels.

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Table 2

Flowering time of 35S::gene B T1 transgenic plants

	Flowering time	Relative expression level of gene B mRNA
C24	30 d	1
B4	18 d	> 10
B5	18 d	> 10
B11	> 80 d	> 10
B12	> 80 d	> 10
Landsberg <i>erecta</i>	20 d	n.d.
B36	> 80 d	> 10
B45	> 80 d	> 10
<i>flf</i>	> 80 d	2

5                    Transformant seeds, harvested from *in planta*  
transformed plants, were selected on MS plates containing  
50 µg/ml kanamycin. Kanamycin resistant T1 seedlings were  
transferred to soil at 20 d. The level of gene B  
transcript was determined in kanamycin resistant T2 plants  
10 for B2 and B5, and from young leaves from the T1 late-  
flowering plants (B11, B12, B36, B45). n.d.: not  
detectable.

15                    It is surprising that over-expression of gene B  
gave two completely opposite phenotypes. In order to  
clarify this, we generated transgenics containing gene B  
under the control of the 35S promoter in ecotype Landsberg  
*erecta*. Of the 24 T1 lines generated, none flowered  
earlier than wild-type Landsberg *erecta*, 12 had not bolted  
20 after 70 days, and 3 bolted after about 40 days, compared  
with 25 days for Landsberg *erecta*. Two of the three lines  
which bolted after 40 days exhibited floral abnormalities  
and partial sterility. Total RNA was isolated from rosette

- 30 -

leaves of two non-flowering T1 plants (B36, B45; Table 1), both of which had high expression levels of the transgene.

Therefore in Landsberg erecta over-expression of gene B causes a delay in flowering time, whereas in C24 it causes either a delay in flowering, or causes the plants to flower significantly earlier. This may be mediated by a dominant negative effect or by a form of post-transcriptional gene silencing. Analysis of protein expression levels is being pursued in order to clarify this point. Presumably a difference in the genetic background of the two ecotypes is responsible for the difference observed between ecotypes.

These results demonstrate that over-expression of gene B causes late-flowering, whereas gene A has little effect on flowering time, indicating that over-expression of gene B is the most likely cause of the late-flowering *flf* phenotype and that this gene encodes a dosage-dependent repressor of flowering. Gene B will hereafter be referred to as *FLF*.

#### Example 13      Anti-Sense Constructs

Anti-sense plant constructs have been generated using an anti-sense *FLF* gene construct under the control of the CaMV 35S promoter. A 35S::*FLF* antisense binary construct was generated by cloning the EcoRI/SpeI digested PCR product amplified with primers

CGGAATTCTCACACGAATAAGGTAC and

GGACTAGTGGTCAAGATCCTTGATC

as described for the 35S::*FLF* construct. This amplified the region downstream of the MADS box, so that the antisense construct lacks the MADS box region. The PCR product was cloned into pART7 and pBART 27 (which is a derivative of pART27), and transgenic plants were generated as described above, except that the *Bar* gene was used as the selectable marker.

25 T1 C24 transgenic plants were generated with a construct in which the 3' end of the *FLF* gene, in the

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antisense orientation, was under the control of a 35S promoter (35S::*FLFAS*). Approximately half of the T1 plants had flowered before 20 days of growth, compared to 30 days for the non-transformed strain

5 Transgenic plants were produced in the C24 and the Columbia ecotypes. Of the six T1 plants produced in the Columbia ecotype, three bolted earlier than wild-type Columbia. Wild-type C24 plants bolt at about 30 days, and wild-type Columbia plants bolt at about 20 days.

10 These results indicate that the antisense construct acts to decrease flowering time, presumably by decreasing the level of the *FLF* transcript.

RNA gel blot analysis of early-flowering plants from three T2 C24 antisense lines revealed that the level  
15 of *FLF* transcript was considerably lower than in non-transformed C24, confirming that the antisense construct was acting to decrease flowering time by decreasing the level of *FLF* transcript.

20 Example 14 The *FLF* Gene Is A Novel MADS Box Gene

The *FLF* cDNA sequence has strong homology to a class of transcription factors known as MADS box genes. The *FLF* sequence shows greatest similarity to the MADS gene *AGL14* in the M-I-K domain, but over the entire cDNA  
25 sequence it shows greater similarity to *CAL* (*CAULIFLOWER*) and *AP1* (*APETALA1*). The location of the MADS box, I domain, K domain and C terminal domain are indicated in Figure 5A. The K domain is typical of those of other plant MADS genes. Comparison of the genomic sequence (SEQ ID  
30 NO. 1) and cDNA sequence (SEQ ID NO. 2) of the *FLF* gene revealed the presence of 6 introns, with intron I being 3.5 kb. The predicted protein (SEQ ID NO. 3) is 196 amino acids long, which is shorter than the proteins encoded by most MADS box genes.

35 One of the main roles of MADS box genes in plant development which has been described to date is in specifying floral organ identity. Other roles for MADS-box

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genes include specifying root architecture and vegetative growth. To investigate whether *FLF* also has other roles in addition to its role in controlling the time of flowering, we examined its expression in a range of tissues. Figure 5B confirms the high expression of the *FLF* gene in vegetative rosette leaves, and reveals a strong expression in roots and lower expression in floral tissues, suggesting possible further roles for the *FLF* gene. No root phenotype has been observed in the transgenic lines. However, a number of lines had reduced fertility, which appeared to be caused by a lack of pollen in C24 lines or by abnormal carpels in Landsberg erecta lines. However, as the early Ac plants (see later) did not show these phenotypes it is unclear whether this is caused by change in expression of the *FLF* gene.

The expression of the *FLF* gene is lower in post-vegetative tissues than it is in vegetative rosette leaves. We investigated the possibility that reduction in the level of expression of the *FLF* gene accompanies the transition to flowering. RNA was isolated from C24 and *flf* whole plants every 10 days post-sowing, until the stage where the majority of C24 plants had bolted (50 d). The expression of the *FLF* gene remained unaltered in these plants (Figure 5C), suggesting that if reduction in the level of expression of the *FLF* gene does accompany the transition to flowering it must occur in only a few cells.

The *flf* mutant demonstrates a number of similarities to the *lhy* mutant described by Schaffer et al. (1998): they are both (semi-)dominant late-flowering mutants caused by insertion of foreign DNA adjacent to the gene. In wild-type plants the *LHY* gene is expressed for only a few hours around dawn, whereas in the *lhy* mutant, the *LHY* gene is expressed around the clock. Because of the similarities between *flf* and *lhy*, we examined the expression of the *FLF* gene in C24 and *flf* tissue harvested at dawn and dusk of an 8 h photoperiod. Although there was some difference in the expression of the genes between the



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two time points, there was no alteration of this pattern in the mutant.

Example 15      The Late-Flowering Phenotype Of The *flf*  
Mutant Is Suppressed By Vernalization Or By  
Gibberellic Acid Treatment

In a number of late-flowering mutants and ecotypes, low temperature treatment of germinating seed (vernalization) induces early flowering (Napp-Zinn, 1985), with a 4°C treatment for 21 days saturating the vernalization requirement to produce the shortest time to flower (Bagnall, 1992). The effect of vernalization on the time to flowering of hemizygous and homozygous *flf* mutants is shown in Table 2.

Table 2

Flowering Time of Vernalised C24 and Mutant Plants

	LENGTH OF VERNALISATION		
	0 weeks	4 weeks	8 weeks
C24 (wild-type)	25.2 ± 0.2	13.6 ± 0.3	--
Hemizygous <i>flf</i>	71.4 ± 1.2	39.3 ± 3.7	20.2 ± 0.9
Homozygous <i>flf</i>	>150	100.8 ± 10.7	17.6 ± 1.3

Twenty seeds of the *flf* mutant and wild-type C24 were grown aseptically on MS medium in test-tubes, and exposed to either 4 or 8 weeks at 4°C. Non-vernalized plants were grown in soil (20 plants per 20cm pot). All plants were then grown at 23°C under fluorescent lights (16 h light, 8 h dark). The data are presented as the average number of days ( $\pm$  standard errors) until stem elongation, excluding the period of vernalization.

A 28 day treatment at 4°C resulted in a substantial reduction in the flowering time. However, eight weeks at 4°C was required to saturate the

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vernalization response in both hemizygotes and homozygotes to give a flowering time similar to that of the C24 control. This implies that there is an interaction between *FLF* gene expression and a component of the vernalization-  
5 induced pathway.

RNA was extracted from 12 d old C24 seedlings that were either vernalized or were untreated controls, and probed with *FLF* gene-specific probe. Figure 5E shows a dramatic decrease in *FLF* expression in vernalized seedlings  
10 compared with unvernallized seedlings, suggesting that a component of the vernalization signalling pathway controls *FLF* gene expression. Day 1 is the day on which seeds were transferred to the growth room. In *flf* mutant plants the level of transcript was reduced in 3 week vernalized  
15 seedlings, but not to the low levels observed in C24, consistent with its only partial earlier-flowering character.

*FLF* mutant plants vernalized for 8 weeks had a greater reduction of *FLF* transcript, consistent with the  
20 greater reduction in flowering time.

As with other late-flowering vernalization-responsive mutants and ecotypes of *Arabidopsis*, *flf* mutant plants responded to applications of gibberellic acid ( $GA_3$ ) by flowering earlier. Four week-old *flf* homozygotes  
25 treated with 1  $\mu g$  of  $GA_3$  every second day for a total of two weeks flowered two weeks after the final  $GA_3$  application, compared to later than 20 weeks for untreated plants. However, a single treatment of 4 week old plants with 1  $\mu g$  of  $GA_3$  was not sufficient to induce flowering of  
30 *flf*, although this amount of  $GA_3$  induced early flowering of the late-flowering *fca* mutant (Bagnall, 1992), suggesting that *flf* requires a greater amount of  $GA_3$  for floral induction. In contrast to the dramatic effect of vernalization on the expression of the *FLF* gene, exposure  
35 of either C24 or *flf* seedlings to  $10^{-5}$  M  $GA_3$  had no effect on the expression of the *FLF* gene.

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Example 16      Movement Of An Ac Element Present Within The  
T-DNA Causes Alteration In Flowering Time

Two early flowering plants (M1 plants designated efSL3 and efSL4) were identified from one seedlot comprising bulked seed from *flf* mutant plants. Both plants flowered after 18 days, earlier than C24 which flowered after 30 days. PCR analysis using primers from within the T-DNA sequence and flanking genomic sequence confirmed that these early-flowering plants were derived from the *flf* mutant, and were not contaminants.

The tandem T-DNAs present in the *flf* mutant each contain an Ac element, and we considered the possibility that movement of Ac was the cause of the early-flowering phenotype. DNA was isolated from individual early-flowering M2 progeny of efSL3 and efSL4, digested with EcoRI and probed with the 3' region of Ac. Figure 6A shows the appearance of a new 2.1 kb band in the early-flowering plants, indicating the movement of Ac. The maintenance of the two original Ac bands present within the T-DNAs indicates that the Ac elements have remained in their original positions as well.

In order to determine the new location of Ac, we probed a similar DNA gel blot with probe 4 (Figure 2C), revealing a change in size of the 2.7 kb EcoRI fragment containing the promoter, MADS domain and part of intron I of the *FLF* gene (Figure 6B). The size of the 3' Ac fragment (2.1 kb) indicated that the Ac element had inserted near an EcoRI site, with the 3' end of the Ac nearest the EcoRI site. PCR using a primer in the 3' end of the Ac and primers near the EcoRI sites at either end of the 2.7 kb EcoRI fragment revealed that Ac had inserted within intron I in the *FLF* gene of efSL3. Sequencing of the PCR product determined the precise insertion point of the Ac element (Figure 6C). RNA was isolated from rosette leaves of early-flowering M2 plants and comparable-sized rosette leaves of C24 and *flf* plants, and probed with an *FLF* gene specific riboprobe. As shown in Figure 5d, *FLF*

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gene expression was reduced to approximately 5% of the C24 expression level. It appears that the presence of Ac reduces either the transcriptional efficiency, RNA stability or the splicing efficiency of the transcript, hence reducing the amount of the normally-spliced mRNA, and resulting in early-flowering.

Example 17      Excision of Ac From Intron I Causes Later Flowering and Increased *FLF* Transcript Levels

Twenty progeny of the M1 efSL3 plant were grown and their flowering time recorded. 15 M2 plants flowered at 18 days, the same as their M1 parent; however, 5 plants flowered later than their parent. These later-flowering plants were termed "neo-lates" to distinguish them from the original late-flowering *flf* mutant plants. Their approximate days to bolting were: 50 d (3.2), 50 d (3.4), 60 d (3.5), 85 d (3.5), 100 d (3.1). In the M2 progeny of efSL4, 36 plants flowered at the same time as their M1 parent but one neo-late plant, 4.6, flowered at 38 d. DNA was isolated from individual plants and probed with 3' Ac (Figure 7A). All the neo-lates appeared to be hemizygous for the presence of the 2.1 kb band, indicating hemizygosity for the presence of Ac in intron I. In some cases (3.1, 3.2, 3.3) the Ac element had relocated to a new site, as indicated by the appearance of the new band in Figure 7A.

To demonstrate that in each neo-late plant one copy of the Ac in intron I had excised, PCR was performed using primers derived from intron I sequence, flanking the site of Ac insertion. In each case a PCR product was generated, indicating that at least one copy of Ac had excised. The presence of the 2.1 kb band in Figure 7A indicates that at least one copy of Ac remains in intron I; thus each plant is hemizygous for the presence of Ac in intron I

The neo-late plant 4.6 is homozygous for the loss of the Ac element within the T-DNA closest to *FLF* (gene B).

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We believe that the sector of the M1 early-flowering parent from which the 4.6 seed derived must have been hemizygous for the presence of this Ac element, and plant 4.6 is a homozygous segregant for the loss of this Ac element.

- 5 Presumably the loss of this Ac element was an event independent of that which resulted in the insertion of Ac in intron 1, as M2 progeny of the M1 plant efSL3 are homozygous for the presence of Ac at this location.

- 10 Total RNA was extracted from approximately 80 d old rosette leaves of the neo-lates and the gene B expression level was compared to that of 80 d rosette and cauline leaves of *flf* and 25 d rosette leaves of C24. In all neo-lates the transcript level was higher than that of the early-flowering parent, although lower than that of the  
15 *flf* mutant, consistent with them being hemizygous for the late allele.

- Thus insertion of an Ac element into intron I of *FLF* (gene B) greatly reduces *FLF* (gene B) transcript levels and causes early flowering, and excision of Ac from intron  
20 I restores expression of the *FLF* (gene B) transcript and results in later flowering. This provides compelling evidence that over-expression of *FLF* (gene B) in the late-flowering *flf* mutant is the cause of the late-flowering phenotype.

25

Example 18      The Expression of the *FLF* Gene is Controlled by Known Flowering Time Genes

- In order to further understand the role of the *FLF* gene in the control of flowering we examined its  
30 expression in a range of *Arabidopsis* ecotypes and late-flowering mutants. Figure 8A shows the expression of the *FLF* gene in a variety of ecotypes. Interestingly the *FLF* gene is highly expressed only in ecotypes which have a late allele at the *FRI* locus (Pitztal and C24), and is  
35 particularly highly expressed in C24, but not in ecotypes with an early allele at the *FRI* locus (Columbia, Ws, Landsberg *erecta*).

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It should be noted that the Pitztal seed source used in this experiment was not the late-flowering Pitztal variety. Subsequent analysis of *FLF* expression in the late-flowering Pitztal variety revealed a very high expression level, approximately three times that of C24. This correlates well with the observation that Pitztal takes three times as long to flower as C24 (approximately 90 days compared to approximately 30 days).

To investigate this further, we looked at the expression of the *FLF* gene in the Landsberg erecta ecotype with late alleles of either *FRI* or *FLC* (Figure 8B). Again *FLF* is expressed in the line of Landsberg erecta with the late *FRI*<sup>sf2</sup> allele; however, it is also expressed in lines which contain late *FLC*<sup>sf2</sup> and *FLC*<sup>col</sup> alleles. The expression of the *FLF* gene in Landsberg erecta-*FLC*<sup>col</sup> is interesting, as this plant has the same *FRI* and *FLC* genotype (*FRI*<sup>early</sup>, *FLC*<sup>late</sup>) as the ecotype Columbia, yet there is expression in Landsberg erecta-*FLC*<sup>col</sup>, but not in Columbia. This suggests that Landsberg erecta and Columbia differ in a third, unknown, locus, and that this locus in conjunction with late alleles at the *FLC* locus is able to induce expression of the *FLF* gene, in the absence of a late allele of *FRI*.

Many of the late-flowering mutants are in the Landsberg erecta ecotype, and we looked to see whether the *FLF* gene is upregulated in these mutants. Figure 8C shows that the *FLF* gene is upregulated in the *fca* and *fve* mutants and slightly upregulated in the *fpa* and *fd* mutants in the Landsberg erecta ecotype and in *ld* in Ws ecotype, but not in any of the other late-flowering mutants tested. *FLF* is also upregulated in the *fld* mutant in Columbia ecotype. These data demonstrate that the function of the wild-type alleles of the *FCA*, *FVE*, *FPA*, *LD*, *FD* and *FLD* genes is to down-regulate the *FLF* gene.

We have shown that the higher *FLF* transcript levels in at least one of these mutants, *fca*, is the cause of the late-flowering phenotype, by using the *FLF* antisense construct from Example 13 to decrease both *FLF* transcript

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level in the *fca* mutant and the flowering time of the mutant. We have also shown that a 28 day vernalization period is sufficient to decrease *FLF* transcript in all 6 mutants, and to decrease flowering time. Thus cold-treatment is able to overcome the up-regulation of the *FLC* gene caused by mutations of these loci, and to overcome the delay in flowering.

We also looked at the expression of the *FLF* gene in the mutants *vrn1* and *vrn2*, which have reduced response to vernalization. Both mutants were isolated in the *fca* mutant background, and as *fca* and *vrn2* are closely linked only the *fcavrn2* double mutant is currently available. No increase in expression of the *FLF* gene in *vrn1* was detectable, however, the *vrn2fca* double mutant had increased in *FLF* gene expression over the *fca* mutant level, suggesting that irrespective of any role in the vernalization response, the wild-type *VRN2* gene acts to repress *FLC* expression and thereby promote flowering. *fca vrn1* has a similar flowering time and a similar level of *FLC* transcript to *fca*. Both *fca vrn1* and *fca vrn2* have a smaller reduction in flowering time in response to vernalization than does *fca*, and this is matched by a smaller reduction in *FLC* transcript level. This indicates that the wild-type *VRN1* and *VRN2* genes are involved in mediating the vernalization-induced down-regulation of the *FLC* gene. In our growing conditions *vrn1* segregated away from the *fca* mutant, is late-flowering and shows little vernalization response, in terms of either flowering time or alteration to *FLC* transcript level. This suggests that the *VRN1* gene may be active in an *FLC*-independent pathway as well as in the *FLC*-dependent vernalization pathway.

The expression of the *FLF* gene in early-flowering plants with reduced levels of methylation (Finnegan et al, 1996) is reduced (Figure 5F), suggesting that methylation may play a role in controlling the expression of the *FLF* gene, or a gene which is a regulator of *FLF*.

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Vernalisation, or some component in the vernalisation signal transduction pathway, acts either to suppress *FLF* transcription or to increase *FLF* mRNA degradation. C24 has a strong vernalisation response, with  
5 plants vernalised for 3 weeks flowering in about half the time of unvernalsed plants. A four week vernalisation period decreases *flf* flowering time somewhat, but an eight week period is required to bring flowering back to C24 times. This incomplete effect of short vernalisation  
10 periods on flowering time of the *flf* mutant correlates with the incomplete decrease in transcript levels in *flf*. This suggests that the higher level of the *FLF* transcript, and presumably of the *FLF* protein, titrates out the promoter of flowering produced in response to vernalisation. Longer  
15 periods of vernalisation may produce more of the promoter, which might overcome the higher *FLF* transcript level.

Other ecotypes such as *Ws*, *Landsberg erecta* and *Columbia* show little response to vernalisation; under similar conditions to those which give good response with  
20 C24, the other ecotypes flower only 1 or 2 days early. We note that these ecotypes have very low *FLF* transcript levels, which cannot be decreased much further by vernalisation.

*Pitztal* is a late-flowering ecotype which has a  
25 strong vernalisation response, and has high *FLF* transcript levels. Vernalisation is expected to decrease the level of *FLF* transcript in these plants. Vernalization decreases the level of *FLF* transcript in this ecotype, with longer periods of vernalization resulting in a proportionally  
30 greater decrease in *FLF* transcript, correlating with the decrease in flowering time.

The *flf* mutant requires prolonged GA treatment to cause it to flower early. This suggests that the high levels of *FLF* transcript (and presumably *FLF* protein) may  
35 act to remove GA, or to decrease GA action. Since *FLF* is a MADS box transcription factor, it may do so by activating genes involved in the catabolism of GA, either directly or



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indirectly, or by altering the expression of genes involved in GA signal transduction.

The lack of effect of GA treatment on the level of *FLF* transcript suggests that GA acts either downstream  
 5 of *FLF*, or via another pathway. ie.

VERNALISATION → → decrease in *FLF* transcript → → GA → → FLOWERING  
 OR

VERNALISATION → → decrease in *FLF* transcript → → FLOWERING  
 10 ? → → GA → → FLOWERING

with *FLF* normally acting to block the pathway between VERN and GA

#### 15 *Tissue-Specific Expression*

Levels of expression of *FLF* in different tissues of the C24 ecotype were examined. High expression was observed in vegetative leaves, roots, flower buds and mature flowers. There was a low level of expression in  
 20 cauline leaves and bolt stem, and a very low expression level in green siliques. RNA was isolated from C24 rosette leaves and "apex", ie. the tissue remaining after as many as leaves as possible and the roots were removed; this tissue includes very small leaves and the apical meristem.  
 25 There was no difference in expression level between these two tissue types.

In the *flf* mutant expression of *FLF* was twice that of C24 in vegetative tissue, and expression in floral tissues was relatively greater (about 3 times C24 level).

30 In the Columbia ecotype the level expression vegetative leaves was very low compared to C24, while in floral tissue there was about the same level of expression as C24.

This suggests that there may be a separate  
 35 control of vegetative and floral transcription of the *FLF* gene.

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*Developmental Expression*

As *FLF* appears to be a repressor of flowering, one prediction about its pattern of expression is that it might decrease prior to, or accompanying, the transition to flowering. RNA was extracted from whole plants that were grown on MS medium and harvested every 10 days. Under these conditions 50% of C24 plants were bolting after 50 d. There was no change in the level of *FLF* transcript in either C24 or the *flf* mutant. This suggests that if there is a decrease in the level of *FLF* transcript accompanying the transition to flowering it must occur in very few cells. This result also suggest that there is no decrease in the level of transcript in older leaves, ie. the transcript is not diluted out as the leaf grows.

15

*Circadian Response*

C24 and *flf* plants were grown in 8 h fluorescent photoperiod for 21 d and either maintained in this condition, or transferred to either continuous light or continuous dark. RNA was extracted from plants harvested at either the start or the end of what would have been the 8 h photoperiod. In each case there was slightly higher expression at the earlier time point, suggesting a subtle circadian response. There was no difference in the pattern of expression between the mutant and C24.

25

Example 19      Isolation of a *Brassica napus* *FLF* homologue

Low stringency screening of a *Brassica napus* genomic library with an *FLF* probe lacking the MADS box region resulted in the isolation of 18 strongly-hybridizing plaques out of a total of 72,000 screened. The low stringency conditions were: hybridization at 28°C in 50% formamide, 3 x SSC, 0.1% SDS, 20 x Denhardt's, 50 µg/ml salmon sperm DNA overnight and washed with a final wash of 0.1 x SSC, 0.1% SDS at room temperature. These plaques were purified, and a selection were sequenced as described in Example 4.

35

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The partial genomic sequence of the *Brassica napus* *FLF*-like gene is set out in SEQ ID NO. 4, and the amino acid sequence of the predicted translation product is set out in SEQ ID NO. 5. The partial genomic sequence, showing the location of exons and the sequence of the corresponding translated product, is illustrated in Figure 9, and the sequence of the predicted translated product from the *Brassica napus* gene is compared with the corresponding product from *Arabidopsis thaliana* *FLF* in Figure 10. There is a high degree of conservation, with 79% identity and 83% similarity in the deduced *FLF* protein sequence (as determined by the University of Wisconsin Genetics Computer Group software package version 9.1, using default parameters).

A cDNA library was prepared from *Brassica napus*, and 10 cDNA clones were isolated using hybridisation to an *FLF* cDNA from *Arabidopsis*. The starting RNA was isolated from leaves of *Brassica napus*, cultivar Columbus. Poly(A)+ mRNA was isolated using a mRNA purification kit (Amersham Pharmacia Biotech). A cDNA library was constructed using a SuperScript Choice System cDNA synthesis kit (Gibco BRL) in the lambda-ziplox vector (Gibco BRL) with *EcoRI* arms. The primary titre of the library was approximately 500,000 pfu. Approximately 200,000 plaques from the primary library were screened, using the *Arabidopsis* *FLF* cDNA without the first two exons of the coding region. Screening was carried out at high stringency. Thirteen plaques were picked in the first round, and of these 10 were confirmed as positive by a second round of screening at high stringency. These plaques were purified, and a plasmid containing the cDNA was excised from each clone. The complete nucleotide sequence of each clone was determined, and from this the amino acid sequences encoded by each clone were deduced. Multiple sequence alignments were used to determine the relationships between the clones. From both amino acid and nucleotide sequence data it was concluded that the clones represent transcripts from 5 different genes.

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The cDNA sequences and predicted amino acid sequences are set out in SEQ ID NOS: 6 to 15 and SEQ ID NOS: 16 to 23 respectively. The sequences probably represent 5 genes, grouped as follows:

- 5           12.1/16.1
- 15.1/16.2/18.2
- 11.2
- 14.1/18.1/20.1
- 11.3

- 10   The partial genomic sequence and translation in Figure 9 correspond to the cDNAs 12.1/16.1.

Example 20           Expression and Immunodetection of FLF protein

- 15           The FLF protein could be detected on Western blots using antibodies raised to a bacterially expressed protein.

- A truncated FLF protein lacking the first 80 N-terminal amino acid residues and possessing an in-frame N-terminal histidine tag was overexpressed in *E.coli* strain BL21 [DE3] using a pET 22b+ expression vector (Novagen). 1 ml of an overnight bacterial culture was added to 100ml of LB broth containing 50 µg/ml ampicillin and the culture grown to an OD<sub>600nm</sub> of 0.6 at 37°C. 100 µl of 1M IPTG was  
20           then added, and the culture was grown for a further 4 hours before harvesting for protein isolation. Histidine-tagged protein was purified using Talon metal affinity resin (Clontech). The purified protein was injected into a rabbit for antibody production (Harlow and Lane, 1988).

- 30           Twelve day old *Arabidopsis* plants were ground in liquid nitrogen and homogenised in extraction buffer (0.1M NaPO<sub>4</sub> pH 7.2, 1mM EDTA). Insoluble material was pelleted by centrifugation at 16,000g for 2 minutes. The supernatant was immediately boiled in a one third volume of 6x SDS  
35           sample buffer (0.5M Tris pH 6.8, 10% SDS, 0.6M DTT, 0.012% bromophenol blue) for 5 minutes. Insoluble proteins were extracted by homogenising and boiling for 5 minutes in 2x

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SDS sample buffer (0.167M Tris pH 6.8, 3.3% SDS, 0.2M DTT, 0.004% bromophenol blue). Protein extracts (50 µg per lane) were separated on a denaturing 12% polyacrylamide gel before blotting onto a Protran nitrocellulose membrane (Schleicher & Schuell). Blots were incubated with either preimmune serum diluted 1:1000 or with FLF polyclonal antiserum diluted 1:3000. The immunoreactive protein was visualised using the ECL western blotting analysis system (Amersham) with the secondary antibody diluted 1:2000. The blots were exposed to X-ray film (Fuji RX) for 2 to 10 minutes.

The amount of *FLF* protein was dramatically decreased following 35 days of low temperature treatment in the C24 and Pitztal ecotypes and in the *flf* mutant. The decrease in the *flf* mutant was not as great as in the two ecotypes, and this finding was consistent with our results for both flowering time and *FLF* RNA transcription. There was very little *FLF* protein in either the Landsberg *erecta* ecotype or in the *efSL4* loss-of-function mutant, also consistent with the RNA data. These results suggest that protein expression parallels RNA expression, and that differences seen in the RNA transcript levels will be reflected in protein levels.

These results also demonstrate that immunoassay using antibody directed against *FLF* protein can be used to identify plants having either low or high level expression of this protein, and to select strains having the desired characteristics. Such immunoassays can also be used to monitor recombinant expression of the protein in bacterial or other hosts.

#### Example 21      Effect of transformation with *FLF* on Flowering Time in *Brassica napus*

A cassette containing the *Arabidopsis FLF* cDNA under the control of the Cauliflower Mosaic Virus (CaMV) 35S promoter was inserted into the vector pWBVec8. This vector contains the *HPT* gene, which confers resistance to

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the antibiotic hygromycin, also under the control of the CaMV 35S gene. The plasmid, in the *Agrobacterium tumefaciens* strain AGL1, was used to transform *Brassica napus* cultivar BLN1239 hypocotyl explants, and plants were  
5 regenerated. Hygromycin-resistant T<sub>0</sub> plants were transferred to soil. Approximately four months after the transformation experiment was begun, plants were transferred to small soil pots on a misting bench, and after approximately four weeks the plants were transferred to large pots and put in a  
10 glasshouse.

Plants were regenerated from 21 independent calli. All the plants regenerated from each callus are referred to herein as a family, and each family represents  
1 or more independent transformation events.

15 The morphology of the plants was monitored, and the results are summarised in Table 3.

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Table 3

Family	Clones	Date recorded floral (and leaf no.). Floral status recorded on Days 1, 11, 25, 33 and 41.	PCR test for transgene	Antibody test for Arabidopsis FLF protein
CS Ex 1.1	/1	Small plant	-ve	-ve
	/2	Day 1	-ve	-ve
	/3	Day 1	-ve	-ve
	/4	Day 1	-ve	-ve
	/5	Day 11	-ve	-ve
CS Ex 1.2	/1	Day 25. 17 leaves	+ve	+ve
	/2	Day 33. 15 leaves	+ve	nd
	/3	Day 11	-ve	-ve
	/4	Day 33. 17 leaves	-ve (false -ve ?)	+ve
	/5	Day 25	+ve	+ve
CS Ex 1.3	/1	Day 41. 21 leaves	+ve	+ve
	/2	Day 41. 21 leaves	+ve	+ve
	/3	Day 1	-ve	-ve
CS Ex 1.4	/1	Day 1	-ve	-ve
	/2	Day 1	-ve	-ve
CS Ex 1.5	/1	Day 1	-ve	-ve
CS Ex 1.6	/1	Day 33. 15 leaves	+ve	+ve
CS Ex 1.7	/1	Day 33. 20 leaves	+ve	+ve
	/2	Day 33. 17 leaves	nd	+ve
	/3	Day 33. 19 leaves	+ve	+ve
	/4	Day 33. 16 leaves	+ve	+ve
	/5	Day 11	+ve	nd
CS Ex 1.8	/1	Day 41. 24 leaves	+ve	nd
	/2	Day 41. 22 leaves	+ve	+ve
	/3	Day 41. 24 leaves	+ve	+ve
	/4	Day 41. 23 leaves	+ve	nd
	/5	Day 41. 24 leaves	+ve	nd
CS Ex 1.9	/1	Day 25. 15 leaves	Nd	+ve
CS Ex 1.10	/1	Day 25	+ve	-ve
CS Ex 1.11	/1	Day 25	+ve	nd
	/2	Day 25	-ve	-ve
CS Ex 1.12	/1	Day 1	-ve	-ve
CS Ex 1.13	/1	In TC	In TC	In TC
CS Ex 1.14	/1	Day 25	-ve	-ve
	/2	Day 25	-ve	-ve
	/3	Day 25	-ve	-ve

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CS Ex 1.15	/1	Day 33. 15 leaves	+ve	nd
	/2	Day 33. 16 leaves	+ve	+ve
	/3	Day 33. 16 leaves	+ve	nd
CS Ex 1.16	/1	Day 33. 14 leaves	+ve	+ve
CS Ex 1.17	/1	Day 1	+ve	nd
CS Ex 1.18	/1	In TC	In TC	In TC
CS Ex 1.19	/1	Day 25. 15 leaves	+ve	nd
CS Ex 1.20	/1	Discarded	Discarded	Discarded
CS Ex 1.21	In TC	In TC	In TC	In TC

In TC = plants remain in tissue culture stage  
nd = not determined

- 5                   The plants exhibited a range of flowering times, with some plants flowering in tissue culture or while on the misting bench, while others took more than 2 months longer. Polymerase chain reaction (PCR) analysis using primers specific for the CaMV35S::FLF transgene was
- 10 performed to determine which of the putative transgenic plants contained the transgene. An antibody test (Western analysis) was also carried out to determine which plants contain the *Arabidopsis* FLF protein. The antibody does not cross-react with any *Brassica* proteins under the conditions
- 15 used. Although the PCR and antibody tests were single experiments, there is a good correlation between the two tests.

Table 4 summarises these results.



Table 4

Flowering Time in *Brassica napus* Plants Transformed with *FLF*

Days (Taking day of potting as day 1)	Number of floral plants (those with buds or open flowers)	Number of floral PCR or Antibody positive plants	Number of floral plants negative for both PCR and Antibody test	Number of families with vegetative plants (18 families total)
Day 1	10/41	1/26	9/15	13
Day 11	13/41	2/26	11/15	12
Day 25	24/41	9/26	15/15	7
Day 33	32/41	19/26		2
Day 41	41/41	26/26		0

5                   The day of potting into large pots is referred to as day 1. Floral plants are those with buds or open flowers.

10                   Although no wild-type flowering time control could be included in the experiment, due to the tissue culture stage of the experiment, it is reasonable to assume that the earlier flowering plants, which tested negative for the presence of the transgene and of *Arabidopsis* *FLF* protein, flowered at around the time of the wild-type plants. Thus some of the transgenic lines flowered at  
15                   least 6 weeks later than the earliest flowering lines. The delay in time to flowering was also manifested by an increase in the number of leaves which the plant developed before floral buds appeared.

20                   This example demonstrates that transformation with *FLF* can be used to modify the time of flowering. The person skilled in the art will be able to apply these findings to other species of plant.

Example 22      FLF-like Molecules from Arabidopsis  
thaliana

Searching of the *Arabidopsis* genomic sequence database revealed five putative MADS-box encoding genes with a high degree of homology to the FLF protein. One of these genes, designated *FLF-LIKE1*, occurs on the chromosome 1 BAC F22K20 (AC002291), while the other four, designated *FLF-LIKE 2*, *3*, *4* and *5* respectively, occur in a cluster on the two contiguous chromosome 5 P1 clones MXK3 and MQN23 (AB019236 and AB013395).

The amino acid sequences of the FLF-LIKE proteins are shown below, with amino acids identical to corresponding amino acids of the FLF protein depicted in bold type.

FLF-LIKE1 (SEQ ID NO:26):

FLF-LIKE1 (SEQ ID NO:26):  
 MGRRKIEIKRIENKSSRQVTF SKRRNGLIDKARQLSILCESSVAVVVVSASGKLYDSSS  
 GDDISKIIDRYEIQHADELRALDLEEKIQNYLPHKELLETVQSKLEEPNVDNVSVDSL  
 SLEEQLLETALSVSRARKAELMMEYIESLKEKEKLLREENQVLASQMGKNTLLATDDERG  
 MFPGSSSGNKIPETLPLLN.

FLF-LIKE2 (SEQ ID NO:27):

FLF-LIKE2 (SEQ ID NO:27):  
MGRKKVEIKRIENKSSRQVTF SKRRNGLIEKARQLSILCESSIAVLVVSGSGKLYKSAS  
GDNMSKII DRYEIHHADELEALDLAEKTRNYLPLKELLEIVQSKLEESNVDNASVDTLI  
SLEEQLLETALSVTRARKTELMMGEVKS LQKTENLLREENQTLASQVGKKTF LVI EGDRG  
MSWENGSGNKVRETLP LLK.

FLF-LIKE3 (SEQ ID NO:28):

FLF-LIKE3 (SEQ ID NO:28):  
 MGRRKVEIKRIENKSSRQVTFSKRRKGLIEKARQLSILCESSIAVVAVSGSGKLYDSAS  
 GDNMSKIIDRYEIHHADELKALDLAEKIRNYLPHKELLEIVQSKLEESNVDNVSVDSL  
 SMEEQLETALSVIRAKKTELMMEDMKSLQEREKLLIEENQILASQVGKKTFLVIEGDRG  
 MSRENGSGNKVPETLSLLK.

FLF-LIKE4 (SEQ ID NO:29):

FLF-LIKE4 (SEQ ID NO:29):  
 MGRRKVEIKRIENKSSRQVTFCKRRNGLMEKARQLSILCESSVALIIISATGRLYSFSS  
 GDSMAKILSRYELEQADDLKTLDLEEKTLNLYLSHKELLETIQCKIEEAKSDNVSIDCLK  
 SLEEQLKTALSVTRARKTELMELVKTHQEKEKLLREENQSLTNQLIKMGKMKKSVEAE  
 DARAMSPRESSDNKPPETL L L L K .

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FLF-LIKE5 (SEQ ID NO:30):

MGRRRVEIKRIENKSSRQVTFCKRRNGLMEKARQLSILCGSSVALFIVSSTGKLYNSSS  
 GD SMAKIIISRFKIQQADDPETLDLEDKTQDYLSHKELLEIVQRKIEEAKGDNVSIESLI  
 5 SMEEQLKSALSVIRARKTELLMELVKNLQDKEKLLKEKNKVLASEVGKLKKILETGDER  
 AVMSPENSSGHSPPETLPLLK.

Alignments of the full-length deduced amino acid  
 sequence of the FLF-LIKE proteins with the full length FLF  
 10 protein sequence revealed a 65.3 % identity (86.7 %  
 similarity) for FLF-LIKE1, 61.2 % identity (84.2 %  
 similarity) for FLF-LIKE2, 60.7 % identity (84.2 %  
 similarity) for FLF-LIKE3, 60.7 % identity (85.2 %  
 similarity) for FLF-LIKE4 and 56.1 % identity (86.2 %  
 15 similarity) for FLF-LIKE5. In contrast, the published  
*Arabidopsis* MADS-box proteins which are most similar to FLF  
 show only 42.9 % identity (66.3 % similarity) in the case  
 of AGL14 (Rounsley et al., 1995) , 40.3 % identity (75.5 %  
 similarity) for CAL (CAULIFLOWER, Kempin et al., 1995) and  
 20 38.8 % identity (74.0 % similarity) for AP1 (APETALA1,  
 Mandel et al., 1992). (% identity and similarity determined  
 by the Wisconsin Package Version 10.0, Genetics Computer  
 Group (GCG), Madison, Wisc., using default parameters).

cdNA from a chromosome 1 *FLF* -like gene (*FLF*-  
 25 *LIKE1*) was isolated using a RT PCR based method. First  
 strand cDNA was generated from 5 µg of Col-0 total RNA.  
 Reactions were carried out using Superscript II (GIBCO BRL)  
 in a 20 µl volume according to the manufacturer's  
 instructions. *FLF-LIKE1* transcript was amplified by PCR  
 30 using 1µl of the first strand cDNA synthesis reaction as  
 template with primers :

5'-ATTGAATTCGGGCATAACCCTTATCGGAGATTG-3' and  
 5'-AACGGATCCGTTGATGATGGTGGCTAATTGAGCAG-3';

Eco RI and Bam HI restriction sites respectively are  
 35 underlined. The amplification reaction was carried out in a  
 final volume of 40 µl, which contained 2.5 µM of each  
 oligonucleotide primer, 1.0 units of Amplitaq Polymerase  
 (Perkin Elmer) and 250 µM of each of the four

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deoxynucleotides. Conditions for amplification were as follows: 94°C for 2 min, 40 cycles consisting of 15 s denaturation at 94°C, annealing at 55°C for 15 s and polymerisation at 72°C for 1 min, and a final extension at 72°C for 4 min before the temperature was decreased to 25°C. PCR products were purified using QIAquick PCR purification kit (Qiagen), digested with restriction enzymes Eco RI/Bam HI, and ligated into the corresponding restriction sites of a pBIISK+ vector (Stratagene ).

Positive colonies were sequenced using universal primers with the Applied Biosystems Big Dye terminator sequencing mix according to the manufacturer's instructions, and analysed using an Applied Biosystems 377 sequencing machine (Perkin Elmer). cDNA sequences obtained were compared to *Arabidopsis* genomic sequence (BAC F22K20; AC002291). The University of Wisconsin GCG software package was employed for sequence analysis.

A binary construct containing the *FLF-LIKE1* cDNA under the control of a *CaMV 35S* promoter was generated by cloning an Eco RI/Kpn I digested PCR product into an Eco RI/Kpn I pART7 vector (Gleave, 1992) containing a *CaMV 35S* promoter. The PCR product was amplified using 200 pg of the *FLF-LIKE1* cDNA clone as template with primers:

5'-ATTGAATTCGGGCATAACCCTTATCGGAGATTTG-3' and  
5'-CTAGTGGTACCGTTGATGATGGTGGCTAATTGAGC-3';

Eco RI and Kpn I restriction sites respectively are underlined. The amplification reaction was carried out as described above. The cloned PCR product was sequenced to ensure that no mutations had been introduced during the amplification procedure. The *35S::FLF-LIKE1* cassette was then subcloned into pART27 using Not I (Gleave, 1992), and introduced into *Agrobacterium tumefaciens* strain GV3101 by electroporation. Transgenic plants were generated by *in planta* transformation (Bechtold et al., 1993), using the NPT II gene as a selectable marker to identify transgenic plants.

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The 35S::*FLF-LIKE1* construct was transformed into *Arabidopsis thaliana* ecotypes Landsberg *erecta* and C24. Twenty individual T<sub>1</sub> lines were selected for each ecotype, and of these about half showed a late-flowering phenotype. In the Landsberg *erecta* background, 12 out of 20 T<sub>1</sub> plants bolted 3-4 weeks post-germination, consistent with the bolting time of non-transformed wild type plants. The other 8 plants did not bolt until about 7-8 weeks post-germination. Similarly for C24 transformed lines, 9 out of 20 plants bolted about 4-5 weeks post-germination, consistent with the bolting time of wild-type C24 plants, while the other 11 T<sub>1</sub> lines did not bolt until 8-10 weeks post-germination. These data suggest that the *FLF-LIKE1* gene is capable of delaying flowering when overexpressed in *Arabidopsis thaliana* plants, similarly to what we have shown for *FLF*. Furthermore, it seems likely that the overexpression of the other *FLF-LIKE* genes described would have a similar effect on flowering time to that found for both *FLF* and *FLF-LIKE1* genes, especially considering that *FLF-LIKE1* shows greater homology to the other *FLF-LIKE* genes than to *FLF*.

Example 23                      *FLF* Modulates Gibberellic Acid (GA)  
Activity in a Number of Developmental  
Processes

The phenotypic effects of over-expression of the *FLF* transcript were investigated in 35S::*FLF* transgenic *Arabidopsis thaliana*. The ecotypes used and the numbers of T<sub>1</sub> plants examined are indicated below. Many of the phenotypic characteristics found to be modified are known to be associated with growth processes which are controlled or modulated by GA. These include pollen formation, leaf expansion, decreased petiole angle, and trichome formation. It was particularly noteworthy that some of the plants were sterile, while others showed reduced bolt height and internode length, characteristic of a dwarf phenotype, or colour changes associated with the dwarf phenotype.

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The late-flowering *flf* mutant requires much more GA to induce early flowering than wild type plants, suggesting that the *FLF* gene product may act to remove GA or GA activity. As many of the phenotypic abnormalities observed in transgenic plants expressing high levels of the *FLF* transcript can be attributed to an alteration in GA level or activity, it seems likely that this function of *FLF* is not limited to the control of GA activity in relation to the promotion of flowering, but also in relation to other roles of GA. Hence, the *FLF* gene may be useful in regulating GA activity in other aspects of plant growth, including, but not limited to, control of plant architecture and/or fertility.

As well as the effects on flowering time that have been discussed in previous examples, over-expression of the *FLF* coding sequence also produced a number of vegetative and floral phenotypes, which are outlined below.

#### **C24 ecotype (24 T1 plants)**

One early-flowering plant (#6) had the appearance of a semi-dwarf (bolt height reduced, internode length reduced), typical of the GA semi-dwarfs, caused by a reduction but not abolition of GA production in the plant. This plant was sterile.

Several plants (#6, 9, 10, 16, 19, 22, 23) exhibited partial or complete sterility. In several of these plants it appeared that the anthers had not dehisced, and no pollen was visible.

#### **Landsberg erecta ecotype (24 T1 plants)**

Two plants (#59, 63) were sterile or produced very few seeds. These plants had clear floral abnormalities, having petals of reduced size that were greenish in colour, and abnormally-shaped carpels with trichomes ("hairs"). Normally *Arabidopsis* carpels do not have trichomes.

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The leaves of some plants which still have not flowered were reduced in size, resulting in a smaller diameter leaf rosette than normal (#40, 42, 62). Many of the late-flowering plants (#36, 37, 38, 40, 42, 62) were a darker green colour than normal. GA-deficient dwarfs are dark green. Many of the late-flowering plants exhibited regions of bulging in the leaves, suggesting that leaf expansion is not occurring equally in each direction. Many plants had a reduced petiole angle, ie. the leaves were flatter.

**Landsberg erecta.-FLC<sup>sf2</sup> (17 T1 plants)**

Two plants had the appearance of a semi-dwarf (#26, 28). The plants had reduced fertility. One plant (#25) produced very few seeds. This plant had clear floral abnormalities, with petals of reduced size that were greenish in colour, and abnormally-shaped carpels with trichomes.

One plant (#32) which has still not flowered has extremely small rosettes (~15 mm in diameter). Others are small, but not so extremely so (#100, 103). One of the late-flowering plants (#102) was a darker green colour than normal. Many of the late-flowering plants exhibited regions of bulging in the leaves, again suggesting that leaf expansion is not occurring equally in each direction. Many plants had a reduced petiole angle.

**Landsberg erecta-FRI<sup>sf2</sup> (35 T1 plants)**

One plant (#47) had the appearance of a semi-dwarf. This plant had reduced fertility. One plant (#89) produced very few seeds. This plant had clear floral abnormalities: petals of reduced size that were greenish in colour, abnormally-shaped carpels with trichomes. Some of the late-flowering plants (#48, 56) were a darker green colour than normal. Two plants (#97, 98) which have still not flowered, have extremely small rosettes (~15 mm in

- 56 -

diameter). Others are small, but not so extremely so (#51, 53, 78, 93, 95, 96).

Many of the late-flowering plants exhibited regions of bulging in the leaves, suggesting that leaf expansion is not occurring equally in each direction. Many plants had a reduced petiole angle.

**Further phenotypic abnormalities in Ac generated early-flowering mutants**

The early-flowering mutants generated by insertion of Ac into intron 1 have a reduced number of trichomes on their leaves.

It will be apparent to the person skilled in the art that while the invention has been described in some detail for the purposes of clarity and understanding, various modifications and alterations to the embodiments and methods described herein may be made without departing from the scope of the inventive concept disclosed in this specification.

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CLAIMS

1. An isolated nucleic acid molecule comprising a MADS box, which is capable of altering the flowering time of a plant.
- 5 2. An isolated nucleic acid molecule according to Claim 1, in which expression of the nucleic acid molecule in the plant, in the sense orientation under the control of a promoter sequence, is capable of delaying the flowering of the plant.
- 10 3. An isolated nucleic acid molecule according to Claim 1, which is capable of accelerating the flowering of a plant.
4. An isolated nucleic acid molecule according to Claim 3, in which expression of the nucleic acid molecule in the  
15 plant in the anti-sense orientation under the control of a promoter sequence is capable of accelerating the flowering of the plant.
5. An isolated nucleic acid molecule according to Claim 1, which comprises a nucleotide sequence corresponding to  
20 a *FLOWERING LOCUS F (FLF)* gene, or a PCR primer or a biologically active fragment derived therefrom.
6. A nucleic acid molecule according to Claim 1, which comprises
  - 25 (a) the nucleotide sequence set out in any one of SEQ ID NOS. 1, 2, 4, and 6 to 15;
  - (b) a nucleic acid molecule capable of hybridizing thereto under at least low stringency hybridization conditions; or
  - (c) a nucleic acid molecule which has at least  
30 70% sequence identity with a sequence set out in (a).
7. A nucleic acid molecule according to Claim 6, in which the nucleic acid molecule is
  - 35 (a) capable of hybridizing to a nucleotide sequence as set out in any one of SEQ ID NOS: 1, 2, 4, and 6 to 15 under high stringency hybridization conditions; or

- 63 -

(b) has at least 80% sequence identity with a sequence set out in Claim 6(a).

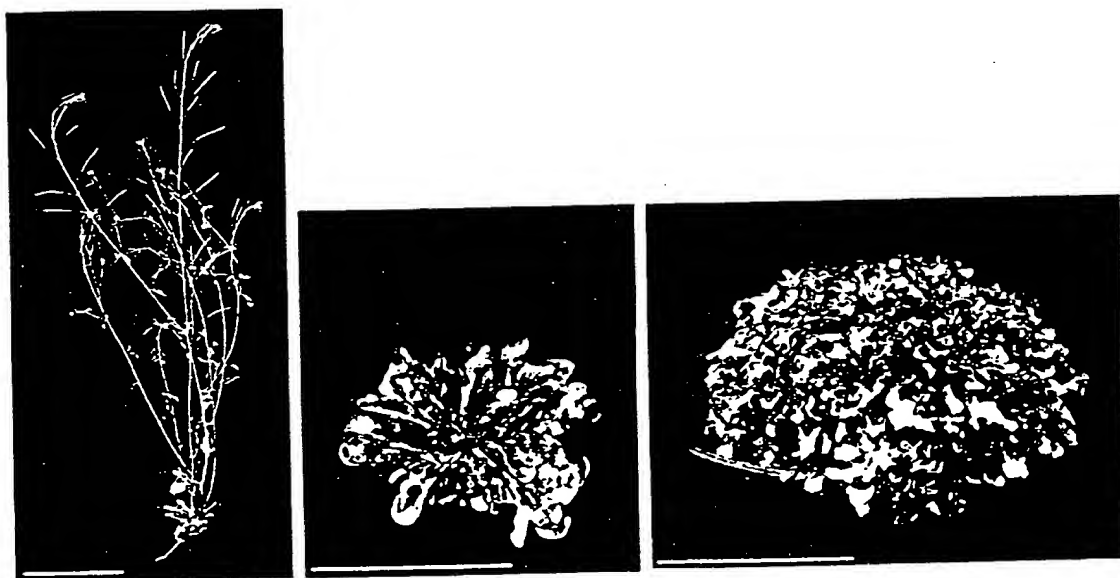
8. A vector comprising a nucleic acid molecule according to any one of Claims 1 to 7.
9. A plant cell transformed with a nucleic acid according to any one of Claims 1 to 7.
10. A plant transformed with a nucleic acid molecule according to any one of Claims 1 to 7.
11. A method of isolating a nucleic acid molecule capable of altering the flowering time of a target plant, comprising the step of using a nucleic acid molecule according to any one of Claims 1 to 7, or a functional portion thereof, as a hybridisation probe or polymerase chain reaction (PCR) primer, and optionally detecting hybridisation.
12. A method according to Claim 11, in which the nucleic acid molecule is capable of hybridizing to a nucleotide sequence as set out in any one of SEQ ID NOS: 1, 2, 4, and 6 to 15 under at least low stringency hybridization conditions.
13. A method of delaying flowering in a plant, comprising the step of introducing a nucleic acid molecule according to any one of Claims 1 to 7 into cells of the plant, optionally such that expression of the nucleic acid molecule is under the control of an inducible promoter, and over-expressing the nucleic acid molecule.
14. A method of inducing early flowering in a plant, comprising the step of reducing the degree of expression of a nucleic acid molecule according to any one of Claims 1 to 7 in the plant.
15. A method of modifying the vegetative and/or floral phenotype of a plant, comprising the step of increasing the level of expression of an *FLF* gene, thereby to modify the level of production or activity of a gibberellin in the plant.

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16. A method of modifying the response of a plant to vernalisation, comprising the step of increasing or decreasing the level of expression of an *FLF* gene.
17. A method according to Claim 15 or Claim 16, in which  
5 the *FLF* gene comprises a nucleic acid molecule according to any one of Claims 1 to 7.
18. A polypeptide encoded by a nucleic acid molecule according to any one of Claim 1 to 7.
19. An *FLF* polypeptide, comprising the amino acid sequence  
10 set out in any one of SEQ ID NOS: 3, 5, and 16 to 30, or having at least 70% sequence identity thereto.
20. An antibody directed against a polypeptide according to Claim 18 or Claim 19.
21. A method of assaying the level of expression of *FLF*  
15 polypeptide, comprising the step of using an antibody according to Claim 20.
22. A method of selecting plants with low or high levels of expression of *FLF*, comprising the step of determining the level of *FLF* mRNA or *FLF* polypeptide in the plant.
- 20 23. A method according to Claim 21, in which the plants are members of a naturally-occurring population.



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*Figure 1*

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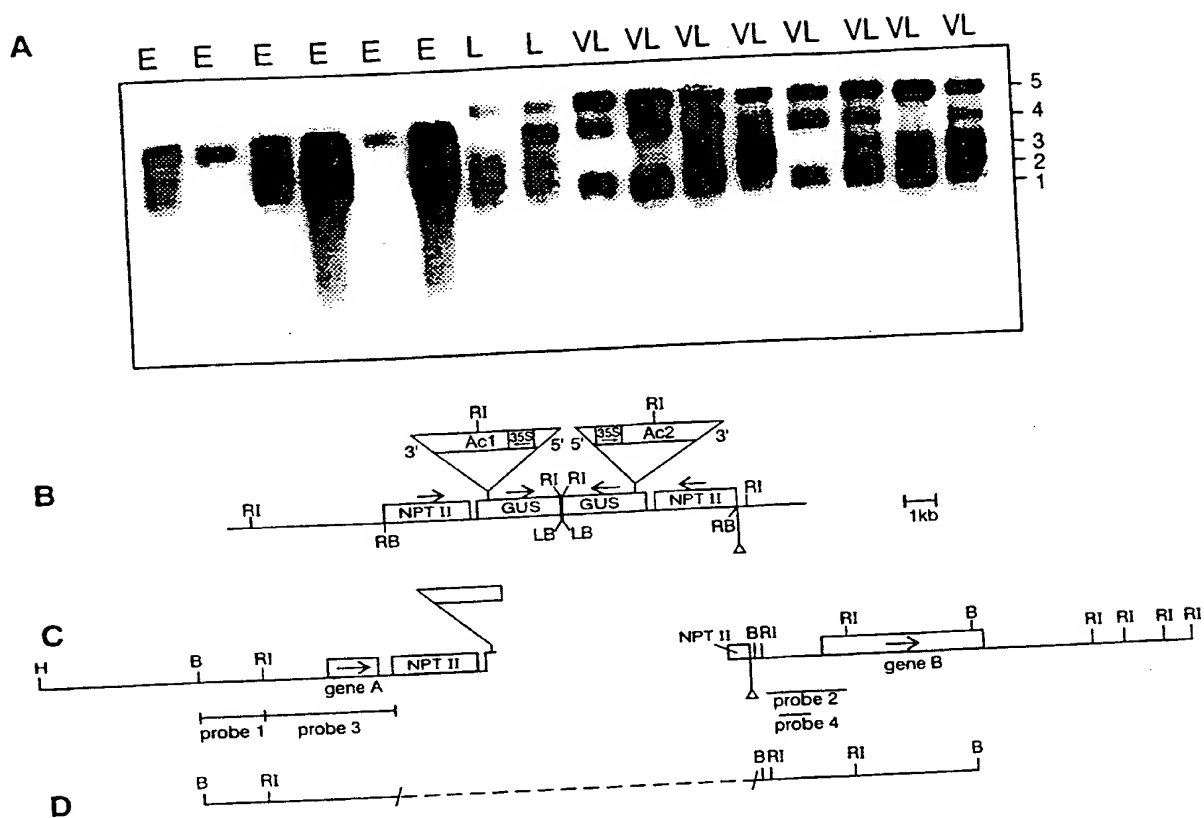
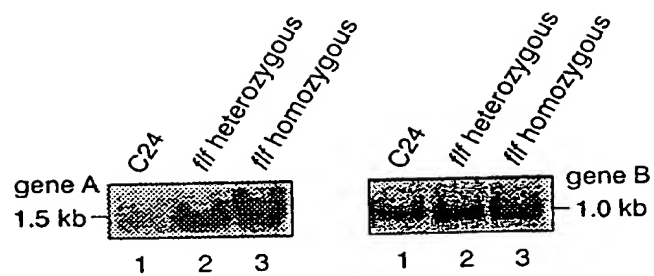
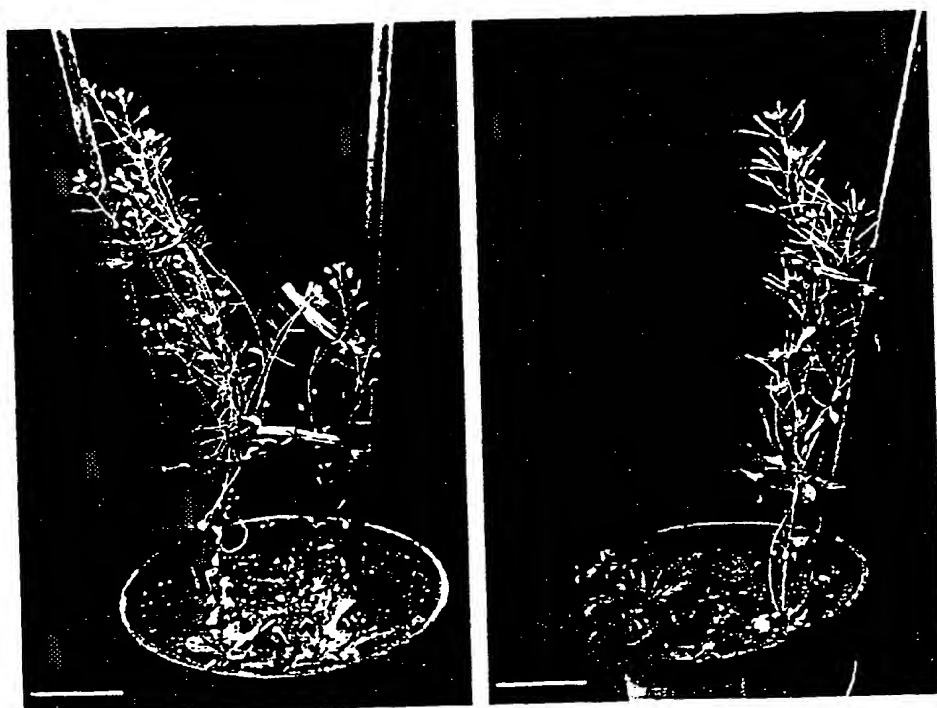


Figure 2

*Figure 3*

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*Figure 4*

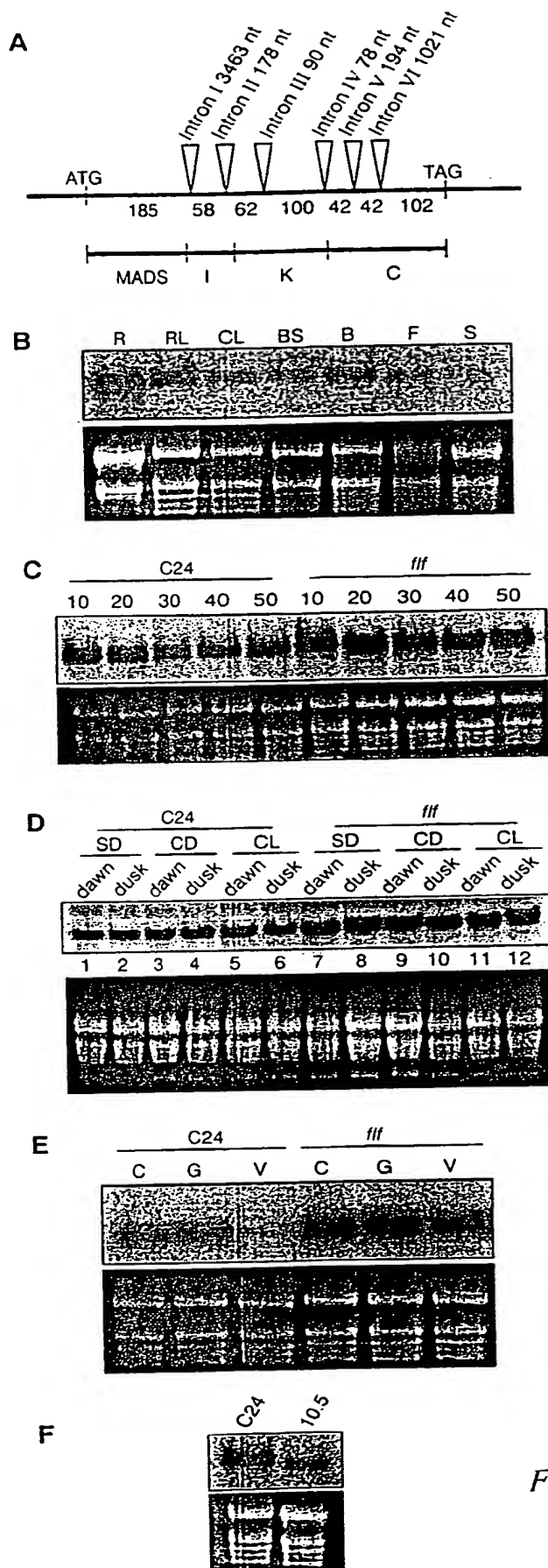


Figure 5

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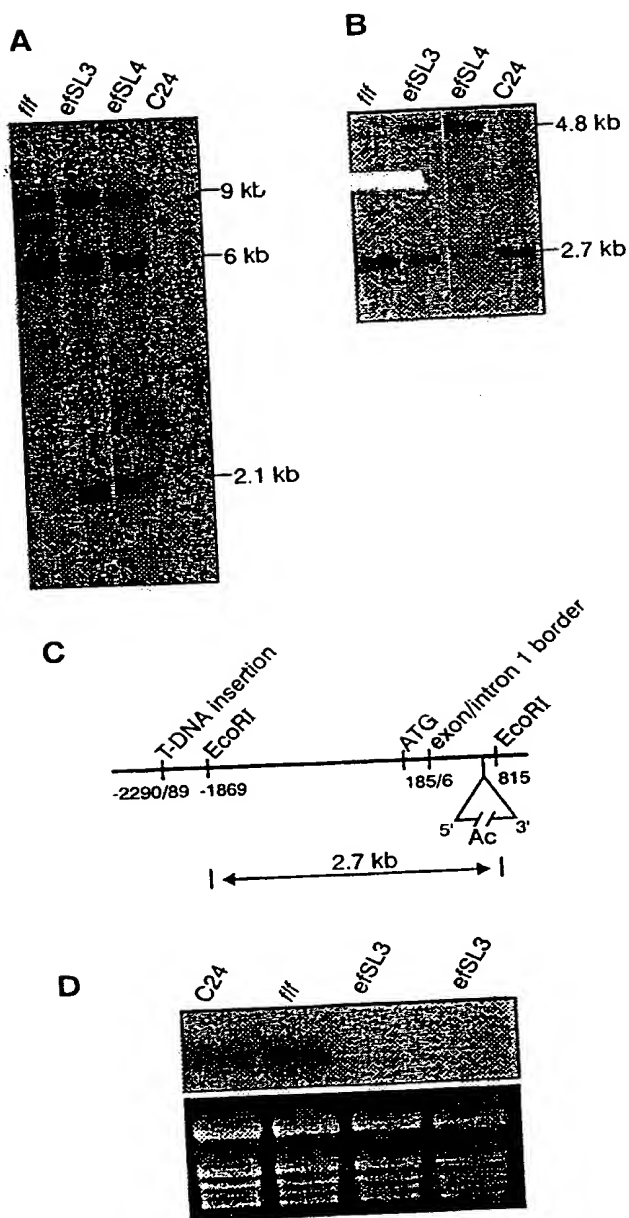
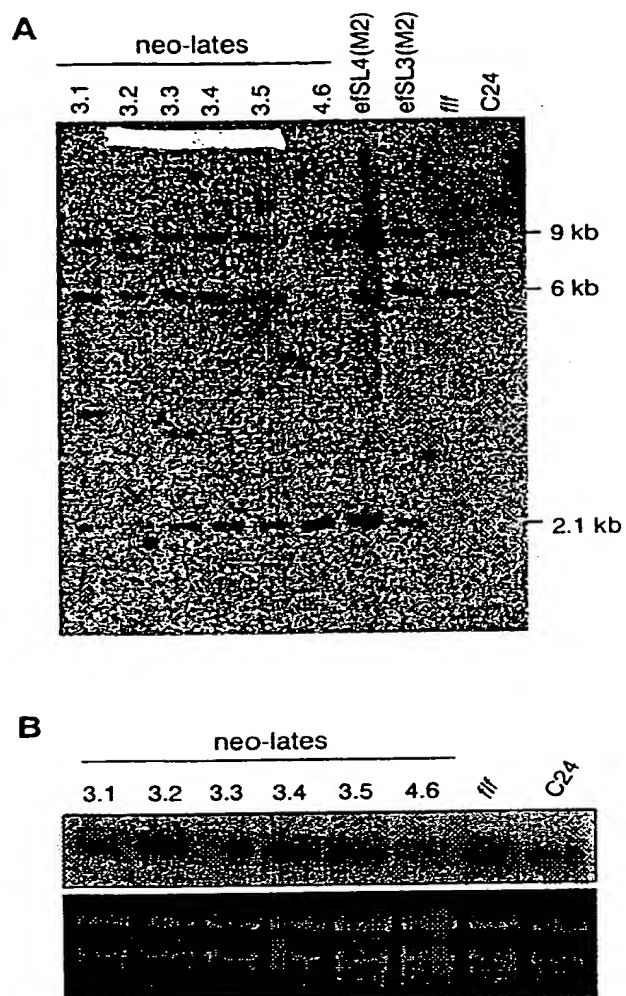


Figure 6

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*Figure 7*

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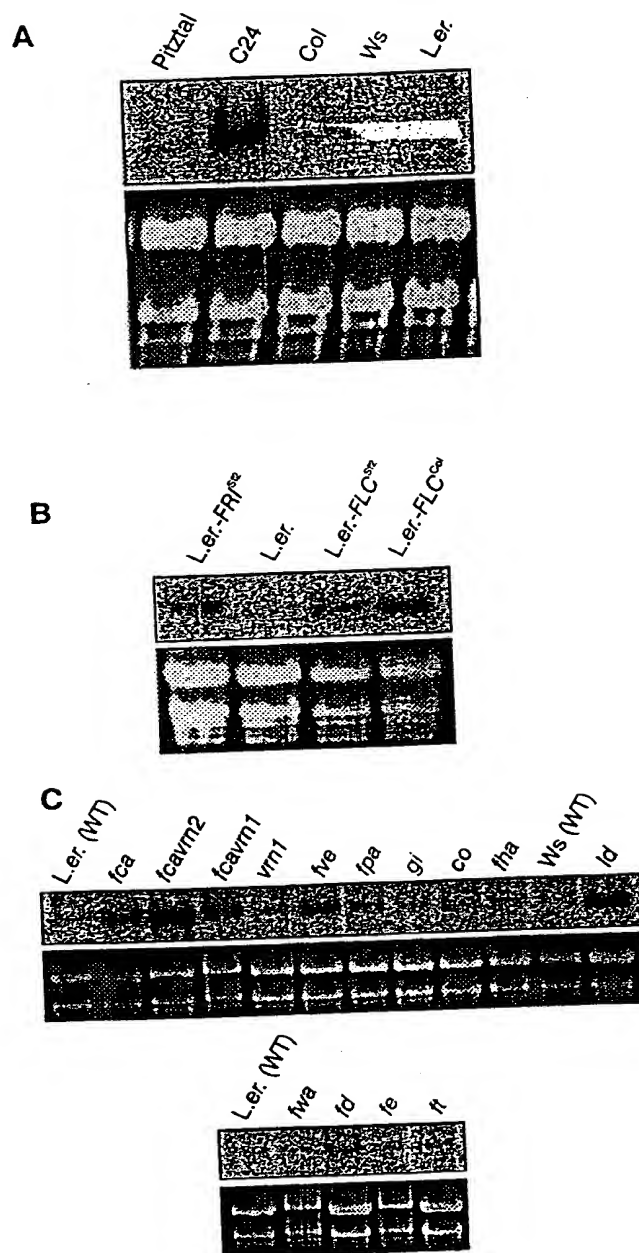


Figure 8



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SEQUENCE LISTING

## (1) GENERAL INFORMATION:

- 5 (i) APPLICANT:  
(A) NAME: COMMONWEALTH SCIENTIFIC AND INDUSTRIAL  
RESEARCH ORGANISATION  
(B) STREET: LIMESTONE AVENUE  
(C) CITY: CAMPBELL  
10 (D) STATE: ACT  
(E) COUNTRY: AUSTRALIA  
(F) POSTAL CODE (ZIP): 2612
- (ii) TITLE OF INVENTION: CONTROL OF FLOWERING  
15
- (iii) NUMBER OF SEQUENCES: 3
- (iv) COMPUTER READABLE FORM:  
(A) MEDIUM TYPE: Floppy disk  
20 (B) COMPUTER: IBM PC compatible  
(C) OPERATING SYSTEM: PC-DOS/MS-DOS  
(D) SOFTWARE: PatentIn Release #1.0, Version #1.30 (EPO)

## 25 (2) INFORMATION FOR SEQ ID NO: 1:

- (i) SEQUENCE CHARACTERISTICS:  
(A) LENGTH: 7968 base pairs  
(B) TYPE: nucleic acid  
30 (C) STRANDEDNESS: single  
(D) TOPOLOGY: linear
- (ii) MOLECULE TYPE: DNA (genomic)
- 35 (iii) HYPOTHETICAL: NO
- (iv) ANTI-SENSE: NO
- (vi) ORIGINAL SOURCE:  
40 (A) ORGANISM: *Arabidopsis thaliana*
- (xi) SEQUENCE DESCRIPTION: SEQ ID NO: 1:

GGATCCAAGA AATAATTTCA TATGGGGCAC AGTTAAAAAA AAAACAATAA  
45 AATGATAATA 60

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5 GGTAATACA ATCCAATTGA AAGTCTTTGT AGGTTTGGTT TGGTCCAATG AAATTGTATG  
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780

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840

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900

30 TTACAAAATT TGTAATCAGT TTCACCCACT TCTTTTCGTC TTGTTACTCG ATATAGCCTC  
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35 ACCTTTCAAG TGTCTAATAT AACACTTTTT AACAAAATAT TACAAAACAA GAAAAATTAT  
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45 AAAATATATA ATAATAAAAT TAGATAAAGA AGAAATTGGT AAAAAATAAT  
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50 TAAAAGGAAA ACAAGCTGAT ACAAGCATTT CACCCAAAAA AAAACAAGCT  
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AAAAAGAATT AGTAACTTTG AGCTATTGCC ATATGTGTGG ACATTTAAGA TTTCTGTAT  
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1440

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5 ATGACGTAGG CGAGTGGTTC TTTGTTTTTA CTATGTAGGC ACGACTTTGG TAACACCTAC  
1560

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10 TCGATATGTC TACATAGTTC AAAGATGATG TAGAGTGGAG GTTCTTTCTG CAATAGTTCA  
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15 AATGCAAAAG TAGCAAAGAC GCTCGTCATG CGGTACACGT GGCAATCTTG TCTTCAAAAC  
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20 1860

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25 CGAGAAAAGG AAAAAAAAAA ATAGAAAGAG AAAACGCTTA GTATCTCCGG  
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30 AAAACTAGAA ATCAAGCGAA TTGAGAACAA AAGTAGCCGA CAAGTCACCT  
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2280

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2400

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50 2460

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- 15 TTATCCAAAT TAGTGTTTTT AATTGATTCA TATTTTTCAT ACACAGTAGT TTTGAATTTT  
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- ACACCTTTTG CTGTACATAA ACTGGTCTAA TTTTAGACTA ATTAAATTTT ATTGTTCTCT  
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- AAGATGAATT GGTAATATAT ACATAATATT TTTAACGAAT TTCTCTCCTT TTTATGGGAT  
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- 35 ATGCTATTTG AAGATTGTCC AAAGGTTTAT AGTTTCCCAC TCTTGCAGTT ACACACATAG  
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- 40 ATTTGCCTCA TATTTATGTG ATTGTATATC AATTATCGCC CTTAATCTTA TCATCGTTGT  
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- GTTCAATTAT GACTTTGTTC CTATTCGTTA AAATTGACAA TCCACAACCT CAATCTTTTG  
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- 45 TTGTGAAAAT CGACAATCAC ACAACCTTTG TATCTTGTGT CTTTGTGCAT GGAAATTGTC  
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- 50 TTCATGTAAG AAATACCAAC CTCTTTGGTA CGGATCTATA ATGAATCAAT ATAATCCTAT  
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3780

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3840

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3900

10 AACCCCTAGT TACTCAGTTA CTCTTTTGC ATACTTAGGT TGATGCAAAG AGCTTAACTT  
3960

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15 GATCTTCTAG GTCAATATGT AGTTTAGTTT TTATCTGTCT TAGTCGCTTC CTTCTATGGA  
4080

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4140

GGGCAGAAAA CTCTTTACTT TTATTGCTTG ATTAATTTGG GGT TAAATA TAGGAAATTG  
4200

25 GAACCTCACA GTTCTATAA ACGAGTATGT AATTGAATGT GAAATAACAA AATGGAAGAC  
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4380

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4740

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55 GGAAGCTCTG AATCTCTGAT AGAGGTTGCA ATTAGAATTA TATAAGTTAA TTTGCAAATG  
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5 AAATTAAGAG AAATATGACT TTCTAGACTC AGTCTGTGTA CTTGGAATTT TACTTCGGTT  
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5040

10 TATATGATTT CTGGAAAAAT AAAAATTGCT TGTTTGCATT TAAGATTGGG GCTGCGTTTA  
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5880

TTACCGCTTC TTCTGTCCCT TTTTCATGGG CAGGATCATC AGTCAAAAGC TCTGAACTAT  
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55 GGTTCACT ATGAGCTACT TGAACCTGTG GATAGGTTAG TACTACTAAC TAAGACTATA  
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7920

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40

## (2) INFORMATION FOR SEQ ID NO: 2:

- 45 (i) SEQUENCE CHARACTERISTICS:  
(A) LENGTH: 943 base pairs  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear
- 50 (ii) MOLECULE TYPE: cDNA
- (iii) HYPOTHETICAL: NO
- 55 (iv) ANTI-SENSE: NO
- (vi) ORIGINAL SOURCE:  
(A) ORGANISM: *Arabidopsis thaliana*



## (xi) SEQUENCE DESCRIPTION: SEQ ID NO: 2:

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10 AAAACTAGAA ATCAAGCGAA TTGAGAACAA AAGTAGCCGA CAAGTCACCT  
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15 TCTTCTCGTC GTCTCCGCCT CCGGCAAGCT CTACAGCTTC TCCTCCGGCG ATAACCTGGT  
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20 360

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540

30 GAATCTTAAA GAAAAGGAGA AAATGCTGAA AGAAGAGAAC CAGGTTTTGG  
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35 CTGGACAAAT 660

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720

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900

ATGAACTTTG TACCTTATTC GTGTGAGAAA AAAAAAAAAA AAA 943  
50

## (2) INFORMATION FOR SEQ ID NO: 3:

- 55 (i) SEQUENCE CHARACTERISTICS:  
(A) LENGTH: 196 amino acids  
(B) TYPE: amino acid  
(C) STRANDEDNESS: single

(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

5 (iii) HYPOTHETICAL: NO

(iv) ANTI-SENSE: NO

(vi) ORIGINAL SOURCE:

10 (A) ORGANISM: *Arabidopsis thaliana*

(xi) SEQUENCE DESCRIPTION: SEQ ID NO: 3:

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Lys Ala Arg Gln Leu Ser Val Leu Cys Asp Ala Ser Val Ala Leu  
25 35 40 45  
Leu Val Val Ser Ala Ser Gly Lys Leu Tyr Ser Phe Ser Ser Gly  
50 55 60  
Asp Asn Leu Val Lys Ile Leu Asp Arg Tyr Gly Lys Gln His Ala  
25 65 70 75  
Asp Asp Leu Lys Ala Leu Asp His Gln Ser Lys Ala Leu Asn Tyr  
30 80 85 90  
Gly Ser His Tyr Glu Leu Leu Glu Leu Val Asp Ser Lys Leu Val  
95 100 105  
Gly Ser Asn Val Lys Asn Val Ser Ile Asp Ala Leu Val Gln Leu  
35 110 115 120  
Glu Glu His Leu Glu Thr Ala Leu Ser Val Thr Arg Ala Lys Lys  
40 125 130 135  
Thr Glu Leu Met Leu Lys Leu Val Glu Asn Leu Lys Glu Lys Glu  
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Lys Met Leu Lys Glu Glu Asn Gln Val Leu Ala Ser Gln Met Glu  
45 155 160 165  
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&lt;110&gt; CSIRO

&lt;120&gt; CONTROL OF FLOWERING

&lt;130&gt; FP10512

&lt;140&gt; PP7469

&lt;141&gt; 1998-12-03

&lt;160&gt; 27

&lt;170&gt; PatentIn Ver. 2.1

&lt;210&gt; 1

&lt;211&gt; 908

&lt;212&gt; DNA

&lt;213&gt; Brassica napus

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&lt;210&gt; 2

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aaanaaa 847

&lt;210&gt; 3

&lt;211&gt; 969

&lt;212&gt; DNA

&lt;213&gt; Brassica napus

&lt;400&gt; 3

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tattaaaaa 969

&lt;210&gt; 4

&lt;211&gt; 868

&lt;212&gt; DNA

&lt;213&gt; Brassica napus

&lt;400&gt; 4

aacgctcagt atctccggct agtggaaacc ggacctcaag atcaaattag ggcgcaaagc 60  
actgttggag acagaagcca tggggaggaa gaaacttgaa atcaagcgaa ttgagaacaa 120  
aagtagccga caagttacct tctctaaacg acgcaacggt ctcacgaga aagctcgtca 180

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gctttccggt ctctgtgaac catccgtcgc tcttcttgtc gtctccgcct ccgggaaact 240
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tgatgatgat cttaaagcct tggatcgta gtcaaaagct ttggactgtg gttcacacca 360
tgagctactg gaacttgttg aaagcaagct tgaggaatca aatgtcgata atgtaagtgt 420
gggttccttg gttcagctgg aggaacacct tgagaacgcc ctctccgtaa caagagctag 480
gaagacagaa ctaatgttga agcttgtcga gaaccttaaa gaaaaggaga agttgctgga 540
agaggagaac catgttttgg ctagccagat ggagaagagt aatcttgtgc gagccgaagc 600
tgataatatg gatgtctcac caggacaaat ctccgacatc aatcttccgg taacgctccc 660
actgttaat tagtcacctt taatcggcga ataaataaaa tccaaaacat ataactaaaa 720
caaacaagat gtgtaattat ccccttgtaa agggtgtacg ttgtataatc tatactctct 780
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atgcaagaca ctttcaaaact taaaaaaa 868

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&lt;210&gt; 5

&lt;211&gt; 792

&lt;212&gt; DNA

&lt;213&gt; Brassica napus

&lt;400&gt; 5

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caaaggcttc tcggagacag aagccatggg aagaaagaaa ctagagatca agcgaattga 60
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tcgtcagctt tcagttctct gcgatgcac cgctcgtctt ctggttgtct cagcctccgg 180
caagctttac aacttctccg ccggcgataa cctgggtcaag atccttgatc gatatggaaa 240
acaacatgct gatgatctta aagctctgga tcttcagtca aaagctccga agtatgggtc 300
acaccatgag ctactagagc ttgtcgaaag taagcttgtg gaatcaaatt ctgatgtaag 360
cgctgactcc ctggttcagc tggaggacca ccttgagact gccctctccg taactagagc 420
taggaagaca gaactaatgt tgaagcttgt tgatagcctc aaagaaaagg agaaattgct 480
gaaagaagag aaccaggggt tggctagcca gatggagaag aataatcttg cgggagccga 540
agctgataaa atggagatgt cacctggaca aatctctgac atcaatcgtc cggtaaactc 600
ccgactgctt tattagccnc cttaagtcca aaacttgtga ctaaaaacaa aaataagtta 660
tcgaactatt cccctataag ggtgaacgtt gtatatcttc attctctctg gctgagagac 720
cccgtgtgta aaactatggt tagatttaag taaaaatata tatttaagac atactaaaaa 780
aaaaaaaaaa aa 792

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&lt;210&gt; 6

&lt;211&gt; 990

&lt;212&gt; DNA

&lt;213&gt; Brassica napus

&lt;400&gt; 6

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gggcacagag accacttggg gacagaaacc atgggaagaa aaaaactaga aatcaagcga 60
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aaagctcgtc agctttctgt tctctgcgat gcatccgtcg cgcttctcgt tgtctcctcc 180
tccggcaagc tctacagctt ctccgccggt gataacctgg tcaggatcct tgatcgatat 240
ggaaaacagc atgctgatga tcttaaagcc ctgaatcttc agtcaaaagc tctgagctat 300
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- 14 -

ggtgtaagcg tggacaccct cgttcagctg gaggggtgtcc ttgaaaatgc cctctctcta 420  
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 aagctgctga aagaagagaa tcaggctttg gctggccaga aggagaagaa gaatcttgcg 540  
 ggagccgaag ctgataatat ggagatgtca cctggacaaa tctccgacat caatcttccg 600  
 gtaactctcc cactgcttaa ttagccaccg ttagacgggg ctgatcaaat taaaaaatcc 660  
 aaaacataca actaaataaa taagctttgt tgtttttcac cctgaaggg tgcacgttgt 720  
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&lt;210&gt; 7

&lt;211&gt; 780

&lt;212&gt; DNA

&lt;213&gt; Brassica napus

&lt;400&gt; 7

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 gagaaagctc gtcagctttc agttctctgc gatgcatccg tcgctcttct cgttgtctca 180  
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 gatgtaagcg tcgactccct cgttcagctg gaggaccacc ttgagactgc cctctccgta 420  
 actagagcta ggaagacaga actaatgttg aagcttggtg atagcctcaa agaaaaggag 480  
 aaattgctga aagaagagaa ccagggtttg gctagccaga tggagaagaa taatcttgcg 540  
 ggagccgaag ctgataaaat ggagatgtca cctggacaaa tctctgacat caatcgctccg 600  
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 ataagttatc gaactattcc cctataaggg tgaacgttgt atatcttcat tctctctggc 720  
 tgagagaccc ccgtgtgtaa actatggnta gatttaagta aaatatatnt ttaagacana 780

&lt;210&gt; 8

&lt;211&gt; 845

&lt;212&gt; DNA

&lt;213&gt; Brassica napus

&lt;400&gt; 8

ctccggctag tggaaaccgg acctcaagat caaattaggg cgcaaagcac tgttggagac 60  
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 agttaccttc tctaaacgac gcaacggctc catcgagaaa gctcgtcagc tttccgttct 180  
 ctgtgacgca tccgtcgtc ttcttgctgt ctccgcctcc gggaaactct acagcttctc 240  
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 taaagccttg gatcgtcagt caaaagcttt ggactgtggg tcacaccatg agctactgga 360  
 acttggtgaa agcaagcttg aggaatcaaa tgtcgataat gtaagtgtgg gttccctggg 420  
 tcagctggag gaacaccttg agaacgcct ctccgtaaca agagctagga agacagaact 480

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aatgttgaag cttgtcgaga accttaaaga aaaggagaag ttgctggaag aggagaacca 540
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tgtctcacca ggacaaatct ccgacatcaa tcttccggta acgctccac tgcttaatta 660
gtcaccttta atcggcgaat aaataaaatc caaacatat aactaaaaca aacaagatgt 720
gtaattatcc ccttgtaaag ggtgtacgtt gtataatcta tactctctct ccggctcgag 780
aggcttcggg tgtaaaacta tttcagattt atgtaagata gaaaatctat gcaagacact 840
ttcaa                                           845

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&lt;210&gt; 9

&lt;211&gt; 825

&lt;212&gt; DNA

&lt;213&gt; Brassica napus

&lt;400&gt; 9

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cggcgagagt tgaaaccgaa tctcaggatc aaattagggc acaaaggctt ctccgagaca 60
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cttgctgaaa gtaagcttgt ggaatcaaat tctgatgtaa gcgtcgactc cctcgttcag 420
ctggaggacc accttgagac tgccctctcc gtaactagag ctaggaagac agaactaatg 480
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tcacctggac aaatctctga catcaatcgt ccggtaaact tccgactgct ttattagcca 660
ccttaagtcc aaaacttgtg actaaaaaca aaaataagtt atcgaactat tccccataaa 720
gggtgaacgt tgtatatctt cattctctct ggctgagaga ccccggtgtg aaaactatgg 780
ttagatttaa gtaaaaatat atatttaaga cataactaaa aaaaa                                           825

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&lt;210&gt; 10

&lt;211&gt; 891

&lt;212&gt; DNA

&lt;213&gt; Brassica napus

&lt;400&gt; 10

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tccggctagt ggaaaccgga cctcaagatc aaattagggc gcaaagcact gttggagaca 60
gaagccatgg ggaggaagaa acttgaaatc aagcgaattg agaacaaaag tagccgacaa 120
gttaccttct ctaaaccgacg caacgggtctc atcgagaaag ctcgtcagct ttccgttctc 180
tgtgacgcat ccgtcgctct tcttgctgctc tccgcctccg ggaaactcta cagcttctcc 240
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cttggtgaaa gcaagcttga ggaatcaaat gtcgataatg taagtgtggg ttccctggtt 420
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atgttgaaagc ttgtcgagaa ccttaaagaa aaggagaagt tgctggaaga ggagaacat 540
gttttggcta gccagatgga gaagagtaat cttgtgctgag ccgaagctga taatatggat 600
gtctcaccag gacaaatctc cgacatcaat cttccggtaa cgctccact gcttaattag 660

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tcaccttttaa tcggcgaata aataaaatcc aaaacatata actaaaacaa acaagatgtg 720  
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 ggcttcgggt gtaaaactat ttcagattta tgtaagatag aaaatctatg caagacactt 840  
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<210> 11

<211> 196

<212> PRT

<213> Brassica napus

<400> 11

Met Gly Arg Lys Lys Leu Glu Ile Lys Arg Ile Glu Asn Lys Ser Ser  
 1 5 10 15

Arg Gln Val Thr Phe Ser Lys Arg Arg Asn Gly Leu Ile Glu Lys Ala  
 20 25 30

Arg Gln Leu Ser Val Leu Cys Asp Ala Ser Val Ala Leu Leu Val Val  
 35 40 45

Ser Ala Ser Gly Lys Leu Tyr Asn Phe Ser Ala Gly Asp Asp Leu Val  
 50 55 60

Lys Ile Val Asp Arg Tyr Gly Lys Gln His Ala Asp Asp Arg Lys Ala  
 65 70 75 80

Leu Asp Leu Gln Ser Glu Ala Pro Lys Tyr Gly Ser His His Glu Leu  
 85 90 95

Leu Glu Leu Val Glu Ser Lys Leu Val Glu Ser Asn Ser Asp Val Ser  
 100 105 110

Val Asp Ser Leu Val Gln Leu Glu Asn His Leu Glu Thr Ala Leu Ser  
 115 120 125

Val Thr Arg Ala Arg Lys Thr Glu Leu Leu Leu Lys Leu Val Asp Ser  
 130 135 140

Leu Lys Glu Lys Glu Lys Leu Leu Lys Glu Glu Asn Gln Gly Leu Ala  
 145 150 155 160

Ser Gln Met Glu Lys Asn Asn Leu Ala Gly Ala Glu Ala Asp Lys Met  
 165 170 175

Glu Val Ser Pro Gly Gln Ile Ser Asp Ile Asn Cys Pro Val Thr Leu  
 180 185 190



Pro Leu Leu Tyr  
195

<210> 12  
<211> 196  
<212> PRT  
<213> Brassica napus

<400> 12  
Met Gly Arg Lys Lys Leu Glu Ile Lys Arg Ile Glu Lys Asn Ser Ser  
1 5 10 15  
Arg Gln Val Thr Phe Cys Lys Arg Arg Asn Gly Leu Ile Glu Lys Ala  
20 25 30  
Arg Gln Leu Ser Val Leu Cys Glu Ala Ser Val Gly Leu Leu Val Val  
35 40 45  
Ser Ala Ser Asp Lys Leu Tyr Ser Phe Ser Ser Gly Asp Arg Leu Glu  
50 55 60  
Lys Ile Leu Asp Arg Tyr Gly Lys Lys His Ala Asp Asp Leu Asn Ala  
65 70 75 80  
Leu Asp Leu Gln Ser Lys Ser Leu Asn Tyr Ser Ser His His Glu Leu  
85 90 95  
Leu Glu Leu Val Glu Ser Lys Leu Val Glu Ser Ile Asp Asp Val Ser  
100 105 110  
Val Asp Ser Leu Val Glu Leu Glu Asp His Leu Glu Thr Ala Leu Ser  
115 120 125  
Val Thr Arg Ala Arg Lys Ala Glu Leu Met Leu Lys Leu Val Glu Ser  
130 135 140  
Leu Lys Glu Lys Glu Asn Leu Leu Lys Glu Glu Asn Gln Val Leu Ala  
145 150 155 160  
Ser Gln Ile Glu Lys Lys Asn Leu Glu Gly Ala Glu Ala Asp Asn Ile  
165 170 175  
Glu Met Ser Ser Gly Gln Ile Ser Asp Ile Asn Leu Pro Val Thr Leu  
180 185 190

Pro Leu Leu Asn  
195

&lt;210&gt; 13

&lt;211&gt; 197

&lt;212&gt; PRT

&lt;213&gt; Brassica napus

&lt;400&gt; 13

Met Gly Arg Lys Lys Leu Glu Ile Lys Arg Ile Glu Asn Lys Ser Ser  
 1 5 10 15

Arg Gln Val Thr Phe Ser Lys Arg Arg Ser Gly Leu Ile Glu Lys Ala  
 20 25 30

Arg Gln Leu Ser Val Leu Cys Asp Ala Ser Val Ala Leu Leu Val Val  
 35 40 45

Ser Ser Ser Gly Lys Leu Tyr Ser Phe Ser Ala Gly Asp Asn Leu Val  
 50 55 60

Arg Ile Leu Asp Arg Tyr Gly Lys Gln His Ala Asp Asp Leu Lys Ala  
 65 70 75 80

Leu Asn Leu Gln Ser Lys Ala Leu Ser Tyr Gly Ser His Asn Glu Leu  
 85 90 95

Leu Glu Leu Val Asp Ser Lys Leu Val Glu Ser Asn Val Gly Gly Val  
 100 105 110

Ser Val Asp Thr Leu Val Gln Leu Glu Gly Val Leu Glu Asn Ala Leu  
 115 120 125

Ser Leu Thr Arg Ala Arg Lys Thr Glu Leu Met Leu Lys Leu Val Asp  
 130 135 140

Ser Leu Lys Glu Lys Glu Lys Leu Leu Lys Glu Glu Asn Gln Ala Leu  
 145 150 155 160

Ala Gly Gln Lys Glu Lys Lys Asn Leu Ala Gly Ala Glu Ala Asp Asn  
 165 170 175

Met Glu Met Ser Pro Gly Gln Ile Ser Asp Ile Asn Leu Pro Val Thr  
 180 185 190

Leu Pro Leu Leu Asn  
 195

&lt;210&gt; 14

&lt;211&gt; 197

&lt;212&gt; PRT

&lt;213&gt; Brassica napus

&lt;400&gt; 14

Met Gly Arg Lys Lys Leu Glu Ile Lys Arg Ile Glu Asn Lys Ser Ser  
1 5 10 15

Arg Gln Val Thr Phe Ser Lys Arg Arg Asn Gly Leu Ile Glu Lys Ala  
20 25 30

Arg Gln Leu Ser Val Leu Cys Asp Ala Ser Val Ala Leu Leu Val Val  
35 40 45

Ser Ala Ser Gly Lys Leu Tyr Ser Phe Ser Ser Gly Asp Asn Leu Val  
50 55 60

Lys Ile Leu Asp Arg Tyr Gly Lys Gln His Asp Asp Asp Leu Lys Ala  
65 70 75 80

Leu Asp Arg Gln Ser Lys Ala Leu Asp Cys Gly Ser His His Glu Leu  
85 90 95

Leu Glu Leu Val Glu Ser Lys Leu Glu Glu Ser Asn Val Asp Asn Val  
100 105 110

Ser Val Gly Ser Leu Val Gln Leu Glu Glu His Leu Glu Asn Ala Leu  
115 120 125

Ser Val Thr Arg Ala Arg Lys Thr Glu Leu Met Leu Lys Leu Val Glu  
130 135 140

Asn Leu Lys Glu Lys Glu Lys Leu Leu Glu Glu Glu Asn His Val Leu  
145 150 155 160

Ala Ser Gln Met Glu Lys Ser Asn Leu Val Arg Ala Glu Ala Asp Asn  
165 170 175

Met Asp Val Ser Pro Gly Gln Ile Ser Asp Ile Asn Leu Pro Val Thr  
180 185 190

Leu Pro Leu Leu Asn  
195

&lt;210&gt; 15

&lt;211&gt; 196

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&lt;212&gt; PRT

&lt;213&gt; Brassica napus

&lt;400&gt; 15

Met Gly Arg Lys Lys Leu Glu Ile Lys Arg Ile Glu Asn Lys Ser Ser  
 1 5 10 15

Arg Gln Val Thr Phe Ser Lys Arg Arg Asn Gly Leu Ile Glu Lys Ala  
 20 25 30

Arg Gln Leu Ser Val Leu Cys Asp Ala Ser Val Ala Leu Leu Val Val  
 35 40 45

Ser Ala Ser Gly Lys Leu Tyr Asn Phe Ser Ala Gly Asp Asn Leu Val  
 50 55 60

Lys Ile Leu Asp Arg Tyr Gly Lys Gln His Ala Asp Asp Leu Lys Ala  
 65 70 75 80

Leu Asp Leu Gln Ser Lys Ala Pro Lys Tyr Gly Ser His His Glu Leu  
 85 90 95

Leu Glu Leu Val Glu Ser Lys Leu Val Glu Ser Asn Ser Asp Val Ser  
 100 105 110

Val Asp Ser Leu Val Gln Leu Glu Asp His Leu Glu Thr Ala Leu Ser  
 115 120 125

Val Thr Arg Ala Arg Lys Thr Glu Leu Met Leu Lys Leu Val Asp Ser  
 130 135 140

Leu Lys Glu Lys Glu Lys Leu Leu Lys Glu Glu Asn Gln Gly Leu Ala  
 145 150 155 160

Ser Gln Met Glu Lys Asn Asn Leu Ala Gly Ala Glu Ala Asp Lys Met  
 165 170 175

Glu Met Ser Pro Gly Gln Ile Ser Asp Ile Asn Arg Pro Val Thr Leu  
 180 185 190

Arg Leu Leu Tyr  
 195

&lt;210&gt; 16

&lt;211&gt; 197

&lt;212&gt; PRT

&lt;213&gt; Brassica napus

&lt;400&gt; 16

Met Gly Arg Lys Lys Leu Glu Ile Lys Arg Ile Glu Asn Lys Ser Ser  
 1 5 10 15

Arg Gln Val Thr Phe Ser Lys Arg Arg Ser Gly Leu Ile Glu Lys Ala  
 20 25 30

Arg Gln Leu Ser Val Leu Cys Asp Ala Ser Val Ala Leu Leu Val Val  
 35 40 45

Ser Ser Ser Gly Lys Leu Tyr Ser Phe Ser Ala Gly Asp Asn Leu Val  
 50 55 60

Arg Ile Leu Asp Arg Tyr Gly Lys Gln His Ala Asp Asp Leu Lys Ala  
 65 70 75 80

Leu Asn Leu Gln Ser Lys Ala Leu Ser Tyr Gly Ser His Asn Glu Leu  
 85 90 95

Leu Glu Leu Val Asp Ser Lys Leu Val Glu Ser Asn Val Gly Gly Val  
 100 105 110

Ser Val Asp Thr Leu Val Gln Leu Glu Gly Val Leu Glu Asn Ala Leu  
 115 120 125

Ser Leu Thr Arg Ala Arg Lys Thr Glu Leu Met Leu Lys Leu Val Asp  
 130 135 140

Ser Leu Lys Glu Lys Glu Lys Leu Leu Lys Glu Glu Asn Gln Ala Leu  
 145 150 155 160

Ala Gly Gln Lys Glu Lys Lys Asn Leu Ala Gly Ala Glu Ala Asp Asn  
 165 170 175

Met Glu Met Ser Pro Gly Gln Ile Ser Asp Ile Asn Leu Pro Val Thr  
 180 185 190

Leu Pro Leu Leu Asn  
 195

&lt;210&gt; 17

&lt;211&gt; 196

&lt;212&gt; PRT

&lt;213&gt; Brassica napus

&lt;400&gt; 17

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Met Gly Arg Lys Lys Leu Glu Ile Lys Arg Ile Glu Asn Lys Ser Ser  
 1 5 10 15

Arg Gln Val Thr Phe Ser Lys Arg Arg Asn Gly Leu Ile Glu Lys Ala  
 20 25 30

Arg Gln Leu Ser Val Leu Cys Asp Ala Ser Val Ala Leu Leu Val Val  
 35 40 45

Ser Ala Ser Gly Lys Leu Tyr Asn Phe Ser Ala Gly Asp Asn Leu Val  
 50 55 60

Lys Ile Leu Asp Arg Tyr Gly Lys Gln His Ala Asp Asp Leu Lys Ala  
 65 70 75 80

Leu Asp Leu Gln Ser Lys Ala Pro Lys Tyr Gly Ser His His Glu Leu  
 85 90 95

Leu Glu Leu Val Glu Ser Lys Leu Val Glu Ser Asn Ser Asp Val Ser  
 100 105 110

Val Asp Ser Leu Val Gln Leu Glu Asp His Leu Glu Thr Ala Leu Ser  
 115 120 125

Val Thr Arg Ala Arg Lys Thr Glu Leu Met Leu Lys Leu Val Asp Ser  
 130 135 140

Leu Lys Glu Lys Glu Lys Leu Leu Lys Glu Glu Asn Gln Gly Leu Ala  
 145 150 155 160

Ser Gln Met Glu Lys Asn Asn Leu Ala Gly Ala Glu Ala Asp Lys Met  
 165 170 175

Glu Met Ser Pro Gly Gln Ile Ser Asp Ile Asn Arg Pro Val Thr Leu  
 180 185 190

Arg Leu Leu Tyr  
 195

&lt;210&gt; 18

&lt;211&gt; 197

&lt;212&gt; PRT

&lt;213&gt; Brassica napus

&lt;400&gt; 18

Met Gly Arg Lys Lys Leu Glu Ile Lys Arg Ile Glu Asn Lys Ser Ser  
 1 5 10 15

Arg Gln Val Thr Phe Ser Lys Arg Arg Asn Gly Leu Ile Glu Lys Ala  
 20 25 30

Arg Gln Leu Ser Val Leu Cys Asp Ala Ser Val Ala Leu Leu Val Val  
 35 40 45

Ser Ala Ser Gly Lys Leu Tyr Ser Phe Ser Ser Gly Asp Asn Leu Val  
 50 55 60

Lys Ile Leu Asp Arg Tyr Gly Lys Gln His Asp Asp Asp Leu Lys Ala  
 65 70 75 80

Leu Asp Arg Gln Ser Lys Ala Leu Asp Cys Gly Ser His His Glu Leu  
 85 90 95

Leu Glu Leu Val Glu Ser Lys Leu Glu Glu Ser Asn Val Asp Asn Val  
 100 105 110

Ser Val Gly Ser Leu Val Gln Leu Glu Glu His Leu Glu Asn Ala Leu  
 115 120 125

Ser Val Thr Arg Ala Arg Lys Thr Glu Leu Met Leu Lys Leu Val Glu  
 130 135 140

Asn Leu Lys Glu Lys Glu Lys Leu Leu Glu Glu Glu Asn His Val Leu  
 145 150 155 160

Ala Ser Gln Met Glu Lys Ser Asn Leu Val Arg Ala Glu Ala Asp Asn  
 165 170 175

Met Asp Val Ser Pro Gly Gln Ile Ser Asp Ile Asn Leu Pro Val Thr  
 180 185 190

Leu Pro Leu Leu Asn  
 195

<210> 19

<211> 196

<212> PRT

<213> Brassica napus

<400> 19

Met Gly Arg Lys Lys Leu Glu Ile Lys Arg Ile Glu Asn Lys Ser Ser  
 1 5 10 15

Arg Gln Val Thr Phe Ser Lys Arg Arg Asn Gly Leu Ile Glu Lys Ala

20 25 30  
 Arg Gln Leu Ser Val Leu Cys Asp Ala Ser Val Ala Leu Leu Val Val  
 35 40 45  
 Ser Ala Ser Gly Lys Leu Tyr Asn Phe Ser Ala Gly Asp Asn Leu Val  
 50 55 60  
 Lys Ile Leu Asp Arg Tyr Gly Lys Gln His Ala Asp Asp Leu Lys Ala  
 65 70 75 80  
 Leu Asp Leu Gln Ser Lys Ala Pro Lys Tyr Gly Ser His His Glu Leu  
 85 90 95  
 Leu Glu Leu Val Glu Ser Lys Leu Val Glu Ser Asn Ser Asp Val Ser  
 100 105 110  
 Val Asp Ser Leu Val Gln Leu Glu Asp His Leu Glu Thr Ala Leu Ser  
 115 120 125  
 Val Thr Arg Ala Arg Lys Thr Glu Leu Met Leu Lys Leu Val Asp Ser  
 130 135 140  
 Leu Lys Glu Lys Glu Lys Leu Leu Lys Glu Glu Asn Gln Gly Leu Ala  
 145 150 155 160  
 Ser Gln Met Glu Lys Asn Asn Leu Ala Gly Ala Glu Ala Asp Lys Met  
 165 170 175  
 Glu Met Ser Pro Gly Gln Ile Ser Asp Ile Asn Arg Pro Val Thr Leu  
 180 185 190  
 Arg Leu Leu Tyr  
 195

&lt;210&gt; 20

&lt;211&gt; 197

&lt;212&gt; PRT

&lt;213&gt; Brassica napus

&lt;400&gt; 20

Met Gly Arg Lys Lys Leu Glu Ile Lys Arg Ile Glu Asn Lys Ser Ser  
 1 5 10 15

Arg Gln Val Thr Phe Ser Lys Arg Arg Asn Gly Leu Ile Glu Lys Ala  
 20 25 30



Arg Gln Leu Ser Val Leu Cys Asp Ala Ser Val Ala Leu Leu Val Val  
 35 40 45

Ser Ala Ser Gly Lys Leu Tyr Ser Phe Ser Ser Gly Asp Asn Leu Val  
 50 55 60

Lys Ile Leu Asp Arg Tyr Gly Lys Gln His Asp Asp Asp Leu Lys Ala  
 65 70 75 80

Leu Asp Arg Gln Ser Lys Ala Leu Asp Cys Gly Ser His His Glu Leu  
 85 90 95

Leu Glu Leu Val Glu Ser Lys Leu Glu Glu Ser Asn Val Asp Asn Val  
 100 105 110

Ser Val Gly Ser Leu Val Gln Leu Glu Glu His Leu Glu Asn Ala Leu  
 115 120 125

Ser Val Thr Arg Ala Arg Lys Thr Glu Leu Met Leu Lys Leu Val Glu  
 130 135 140

Asn Leu Lys Glu Lys Glu Lys Leu Leu Glu Glu Glu Asn His Val Leu  
 145 150 155 160

Ala Ser Gln Met Glu Lys Ser Asn Leu Val Arg Ala Glu Ala Asp Asn  
 165 170 175

Met Asp Val Ser Pro Gly Gln Ile Ser Asp Ile Asn Leu Pro Val Thr  
 180 185 190

Leu Pro Leu Leu Asn  
 195

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<211> 196

<212> PRT

<213> Brassica napus

<400> 21

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Arg Gln Leu Ser Ile Leu Cys Glu Ser Ser Val Ala Val Val Val Val  
 35 40 45

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Ser Ala Ser Gly Lys Leu Tyr Asp Ser Ser Ser Gly Asp Asp Ile Ser  
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Lys Ile Ile Asp Arg Tyr Glu Ile Gln His Ala Asp Glu Leu Arg Ala  
 65 70 75 80

Leu Asp Leu Glu Glu Lys Ile Gln Asn Tyr Leu Pro His Lys Glu Leu  
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Leu Glu Thr Val Gln Ser Lys Leu Glu Glu Pro Asn Val Asp Asn Val  
 100 105 110

Ser Val Asp Ser Leu Ile Ser Leu Glu Glu Gln Leu Glu Thr Ala Leu  
 115 120 125

Ser Val Ser Arg Ala Arg Lys Ala Glu Leu Met Met Glu Tyr Ile Glu  
 130 135 140

Ser Leu Lys Glu Lys Glu Lys Leu Leu Arg Glu Glu Asn Gln Val Leu  
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Ala Ser Gln Met Gly Lys Asn Thr Leu Leu Ala Thr Asp Asp Glu Arg  
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Gly Met Phe Pro Gly Ser Ser Ser Gly Asn Lys Ile Pro Glu Thr Leu  
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Pro Leu Leu Asn  
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&lt;211&gt; 196

&lt;212&gt; PRT

&lt;213&gt; Brassica napus

&lt;400&gt; 22

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Arg Gln Val Thr Phe Ser Lys Arg Arg Lys Gly Leu Ile Glu Lys Ala  
 20 25 30

Arg Gln Leu Ser Ile Leu Cys Glu Ser Ser Ile Ala Val Val Ala Val  
 35 40 45

Ser Gly Ser Gly Lys Leu Tyr Asp Ser Ala Ser Gly Asp Asn Met Ser

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 Lys Ile Ile Asp Arg Tyr Glu Ile His His Ala Asp Glu Leu Lys Ala  
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 Leu Asp Leu Ala Glu Lys Ile Arg Asn Tyr Leu Pro His Lys Glu Leu  
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 Leu Glu Ile Val Gln Ser Lys Leu Glu Glu Ser Asn Val Asp Asn Val  
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 Ser Val Asp Ser Leu Ile Ser Met Glu Glu Gln Leu Glu Thr Ala Leu  
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 Ser Val Ile Arg Ala Lys Lys Thr Glu Leu Met Met Glu Asp Met Lys  
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 Ser Leu Gln Glu Arg Glu Lys Leu Leu Ile Glu Glu Asn Gln Ile Leu  
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 Ala Ser Gln Val Gly Lys Lys Thr Phe Leu Val Ile Glu Gly Asp Arg  
                                     165                                      170                                      175  
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 Ser Leu Leu Lys  
                                     195

&lt;210&gt; 23

&lt;211&gt; 200

&lt;212&gt; PRT

&lt;213&gt; Brassica napus

&lt;400&gt; 23

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 Arg Gln Val Thr Phe Cys Lys Arg Arg Asn Gly Leu Met Glu Lys Ala  
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 Arg Gln Leu Ser Ile Leu Cys Glu Ser Ser Val Ala Leu Ile Ile Ile  
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 Ser Ala Thr Gly Arg Leu Tyr Ser Phe Ser Ser Gly Asp Ser Met Ala  
                                     50                                      55                                      60

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Lys Ile Leu Ser Arg Tyr Glu Leu Glu Gln Ala Asp Asp Leu Lys Thr  
 65 70 75 80  
 Leu Asp Leu Glu Glu Lys Thr Leu Asn Tyr Leu Ser His Lys Glu Leu  
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 Leu Glu Thr Ile Gln Cys Lys Ile Glu Glu Ala Lys Ser Asp Asn Val  
 100 105 110  
 Ser Ile Asp Cys Leu Lys Ser Leu Glu Glu Gln Leu Lys Thr Ala Leu  
 115 120 125  
 Ser Val Thr Arg Ala Arg Lys Thr Glu Leu Met Met Glu Leu Val Lys  
 130 135 140  
 Thr His Gln Glu Lys Glu Lys Leu Leu Arg Glu Glu Asn Gln Ser Leu  
 145 150 155 160  
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 35 40 45  
 Ser Ser Thr Gly Lys Leu Tyr Asn Ser Ser Ser Gly Asp Ser Met Ala  
 50 55 60  
 Lys Ile Ile Ser Arg Phe Lys Ile Gln Gln Ala Asp Asp Pro Glu Thr  
 65 70 75 80

Leu Asp Leu Glu Asp Lys Thr Gln Asp Tyr Leu Ser His Lys Glu Leu  
85 90 95

Leu Glu Ile Val Gln Arg Lys Ile Glu Glu Ala Lys Gly Asp Asn Val  
100 105 110

Ser Ile Glu Ser Leu Ile Ser Met Glu Glu Gln Leu Lys Ser Ala Leu  
115 120 125

Ser Val Ile Arg Ala Arg Lys Thr Glu Leu Leu Met Glu Leu Val Lys  
130 135 140

Asn Leu Gln Asp Lys Glu Lys Leu Leu Lys Glu Lys Asn Lys Val Leu  
145 150 155 160

Ala Ser Glu Val Gly Lys Leu Lys Lys Ile Leu Glu Thr Gly Asp Glu  
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Arg Ala Val Met Ser Pro Glu Asn Ser Ser Gly His Ser Pro Pro Glu  
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Thr Leu Pro Leu Leu Lys  
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<211> 196

<212> PRT

<213> Brassica napus

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Arg Gln Leu Ser Ile Leu Cys Glu Ser Ser Ile Ala Val Leu Val Val  
35 40 45

Ser Gly Ser Gly Lys Leu Tyr Lys Ser Ala Ser Gly Asp Asn Met Ser  
50 55 60

Lys Ile Ile Asp Arg Tyr Glu Ile His His Ala Asp Glu Leu Glu Ala  
65 70 75 80

Leu Asp Leu Ala Glu Lys Thr Arg Asn Tyr Leu Pro Leu Lys Glu Leu

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85 90 95  
 Leu Glu Ile Val Gln Ser Lys Leu Glu Glu Ser Asn Val Asp Asn Ala  
 100 105 110  
 Ser Val Asp Thr Leu Ile Ser Leu Glu Glu Gln Leu Glu Thr Ala Leu  
 115 120 125  
 Ser Val Thr Arg Ala Arg Lys Thr Glu Leu Met Met Gly Glu Val Lys  
 130 135 140  
 Ser Leu Gln Lys Thr Glu Asn Leu Leu Arg Glu Glu Asn Gln Thr Leu  
 145 150 155 160  
 Ala Ser Gln Val Gly Lys Lys Thr Phe Leu Val Ile Glu Gly Asp Arg  
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 Gly Met Ser Trp Glu Asn Gly Ser Gly Asn Lys Val Arg Glu Thr Leu  
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 gcaagcttgt ggaatcaaatt gtcggtggtg taagcgtgga caccctcggt cagctggagg 300  
 gtgtccttga aaatgccttc tctctaacta gagctaggaa ggtacgttga cttcatactg 360  
 tcttctcatt tcttactttg tttgttgaaa cgattgttca cttatattta atttgttgca 420  
 gacagaacta atgttgaagc ttgttgatag cctcaaagaa aagggttagat atatcatata 480  
 tgattttata gcacttcaga tatcttctcg tgtttgaaag cctcaaatat ttatgtgttg 540  
 tattaagtgt ctctaagtgt gctttatgag ctgcgaatca aacttcttca taagtgcac 600  
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<210> 27  
 <211> 68  
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&lt;400&gt; 27

Asn Leu Gln Ser Lys Ala Leu Ser Tyr Gly Ser His Asn Glu Leu Leu  
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Glu Leu Val Asp Ser Lys Leu Val Glu Ser Asn Val Gly Gly Val Ser  
20 25 30

Val Asp Thr Leu Val Gln Leu Glu Gly Val Leu Glu Asn Ala Leu Ser  
35 40 45

Leu Thr Arg Ala Arg Lys Thr Glu Leu Met Leu Lys Leu Val Asp Ser  
50 55 60

Leu Lys Glu Lys  
65

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/AU 99/01079**A. CLASSIFICATION OF SUBJECT MATTER**Int Cl<sup>7</sup>: C12N 15/29

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**Minimum documentation searched (classification system followed by classification symbols)  
**SEE ELECTRONIC DATABASE BOX BELOW**Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
**SEE ELECTRONIC DATABASE BOX BELOW**Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
Medline, Chem Abs, WPID: MADS box, inflorescence, flower, control, development, DNA binding, genes, FLF, flower locus.**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 94/00582 (Centre for Plant Breeding and Reproduction Research) 6 January 1994 see entire document	1-23
X	WO 96/11566 (Washington State University) 25 April 1996 see entire document	1-23
PX	SHELDON, C.C et al (March 1999) "The <i>FLF</i> MADS Box Gene: A Repressor of Flowering in Arabidopsis Regulated by Vernalization and Methylation" <i>The Plant Cell</i> , vol. 11, pages 445-458. see entire document	1-23

☐ Further documents are listed in the continuation of Box C☒ See patent family annex

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance  
"E" earlier application or patent but published on or after the international filing date  
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)  
"O" document referring to an oral disclosure, use, exhibition or other means  
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention  
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone  
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art  
"&" document member of the same patent family

Date of the actual completion of the international search  
9 February 2000Date of mailing of the international search report  
11 FEB 2000Name and mailing address of the ISA/AU  
AUSTRALIAN PATENT OFFICE  
PO BOX 200, WODEN ACT 2606, AUSTRALIA  
E-mail address: pct@ipaustalia.gov.au  
Facsimile No. (02) 6285 3929

Authorized officer

PHILIPPA WYRDEMAN  
Telephone No.: (02) 6283 2554



# INTERNATIONAL SEARCH REPORT

## Information on patent family members

International application No.  
**PCT/AU 99/01079**

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report	Patent Family Member
WO 96/11566 AU 39569/95 EP 784425	
WO 94/00582 EP 672155	
END OF ANNEX	

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